

A Cross-Sectional Analysis
of Functional Movement Screen Scores in
Male AAA Minor Hockey Players

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ABSTRACT

The Functional Movement Screen (FMS) has been used as a screening tool to assess inefficiencies and asymmetries associated with movement patterns that could potentially lead to injury risks in athletic populations (Kiesel, Plisky, & Voight, 2007; Parenteau-G et al., 2014; Mokha et al., 2016). The primary purpose of the study was to compare FMS scores across four hockey-specific chronological age groups and five stages of maturity in adolescent male ice-hockey players. The secondary purpose of the study was to determine if years of experience in a specific sport, correlated with movement pattern asymmetries. One hundred and eleven male (9-17 years) AAA players completed a battery of physical measurements including; height (cm), weight (kg), grip strength (kg), sit and reach (cm) and the FMS. FMS scores were analyzed by total score (TS), FMS subgroups (FMS_{movement}, FMS_{flexibility} and FMS_{stability}), frequencies of individual movement pattern scores and left/right asymmetries. Significant differences in FMS TS were revealed across both chronological age, categorized by hockey age groups ($F(3,107) = 7.002$, $p < .001$) and stage of maturity ($F(4,106) = 4.790$, $p < .001$), suggesting that FMS TS improved with both age and physical maturity. However, ANCOVA results revealed no significant differences across hockey age groups ($F(3,106) = 1.917$, $p = .131$), when maturity was entered as a covariate, suggesting that maturity did not influence FMS TS beyond the effect age. FMS sub-groups revealed significant differences in FMS_{move} and FMS_{stab} across both hockey age group and stage of maturity. No significant differences were found in the frequencies of individual screen scores or left/right asymmetries across hockey age groups or stages of maturity. Therefore, the results did not support the assumption of hockey being a significant unilateral training stimulus.

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ABBREVIATIONS

APHV = Age of peak height velocity

CA = Chronological age

CI= Confidence interval

CS4L = Canadian Sport 4 Life

FMS = Functional Movement Screen

FMS_{move} = FMS movement (deep squat, hurdle step, in-line lunge)

FMS_{flex} = FMS flexibility (shoulder mobility, active straight leg raise)

FMS_{stab} = FMS stability (trunk stability push-up, rotary stability)

FMS TS= Total Score (of functional movement screen)

GS = Grip strength

ICC= Intra-class correlation coefficient

M = Mean

OMHA = Ontario Minor Hockey Association

PHV = Peak height velocity

PHVMO = Peak height velocity maturity off-set

RUS = Radius, Ulna and Short bone

SA = Skeletal age

SD = Standard Deviation

SLJ = Standing Long Jump

SM = Sexual Maturity

TW = Tanner and Whitehouse (Stages of maturity)

1 RM = Repetition maximum testing

Functional Movement Screen (Individual Movement Pattern Abbreviations):

DS = Deep Squat

HS = Hurdle Step

ILL = In-Line Lunge

SM = Shoulder Mobility

ASLR = Active Straight Leg Raise

TSPU = Trunk Stability Push-up

RS = Rotary Stability

CHAPTER 1: INTRODUCTION

The Functional Movement Screen (FMS) has been used as a screening tool to assess inefficiencies and asymmetries associated with movement patterns that could potentially lead to injury risks in athletic populations (Kiesel, Plisky, & Voight, 2007; Parenteau-G et al., 2014; Mokha et al., 2016; Avery, M. et al., 2018). The FMS consists of seven full body movement patterns that require varying degrees of muscular strength, stability, flexibility, coordination, and proprioception to execute with a level of proficiency (Cook, Burton, & Hoogenboom, 2006a). Performance of each movement pattern is assigned a score between 0 and 3 based on an individual's ability to maintain posture throughout a range of motion. Scores are summed to calculate a total score (TS) out of a potential 21 points. Total scores, frequency of individual scores (1, 2, 3), and frequency of left/right asymmetries are used to interpret efficiency of movement and risk associated with the potential for injury. Research conducted in adult athletic populations has identified that an FMS total score of 14 or less (out of a possible 21 points) suggests that the individual is at a higher risk of injury (Kiesel, Plisky, & Voight, 2007). However, other studies have not supported the cut-off score of 14 or less as a predictor of potential injury risk. (Dossa et al., 2014; Bardenett et al., 2015; Mokha, Sprague, & Gatens, 2016). More specifically, Mokha, Sprague and Gatens (2016) argue that an analysis of frequency of individual movement scores and/or frequency of asymmetries may be a more valuable injury predictor and allow for a more comprehensive interpretation of the FMS data in adult populations.

The application and interpretation of FMS in an adolescent population becomes more complicated given that the interpretation of FMS scoring does not take into

consideration physical maturity, growth, and development. As adolescents develop, they experience increasing limb length, body weight, and muscle mass, which could potentially influence the efficiency of movement patterns (Quatman-Yates, Quatman, Meszaros, Paterno, & Hewett, 2012). Although research addressing the use of the FMS in an adolescent population is limited, attempts have been made to evaluate FMS scoring and provide some insight into the interpretation of FMS scores relative to maturity (Parenteau-G et al., 2014; Portas et al., 2016; Lloyd et al., 2015; Boguszewski et al., 2017). A common recommendation across most studies conducted on youth, suggests that it is important to consider an individuals' maturity stage in relation to biological age as opposed to chronological age alone. That said, it does not change the scoring criteria or implementation of the FMS. Despite challenges in interpretation, the FMS screen has been deemed reliable when used in youth populations (Parenteau-G et al., 2014). Parenteau-G et al. (2014) screened 28 elite level male hockey players (13-16 years old) to determine the inter-rater and intra-rater reliability of the FMS. They found video raters demonstrated excellent intra-rater reliability ($ICC = 0.96$) and, more importantly, field raters achieved excellent inter-rater reliability for FMS TS with an ICC of 0.96

Stages of maturity have traditionally been calculated using skeletal age, sexual maturation, or age of peak height velocity (APHV). APHV is a non-invasive, field-based assessment using anthropometric measures to determine predicted \pm years away from the age of peak height velocity. The APHV is the preferred method of assessment because of its applicability and convenience. Longitudinal research conducted by Mirwald, Baxter-Jones, Bailey and Beunen (2002) used APHV to calculate somatic maturity and permits comparisons within and across stages of maturation. The APHV equation has been

validated for both males and females with standard error of estimates reported as 0.57 and 0.59 years, respectively (Mirwald et al., 2002).

It has been demonstrated that technical, sport-specific movement patterns in competitive sport can lead to biomechanical adaptations and inefficient movement patterns or asymmetries (i.e., right/left side dominant sport) (Douda, Laparidis, & Tokmakidis, 2002). Athletes who participate in activities that include repetitive, one-sided, sport-specific movements can be at a higher risk of developing inefficient movement patterns (Douda, Laparidis, & Tokmakidis, 2002). For example, volleyball attackers, such as outside hitters, middle blockers and opposite side hitters, have reported that they experienced significantly more shoulder pain than setters or liberos (64% versus 49% respectively) due to the repetitive shoulder rotation associated with their position (Reeser et al., 2010). Therefore, interpreting left/right asymmetries as defined by the FMS may provide valuable insight on the relationship between years of sport specific movement patterns and the development of inefficient movements through frequently practiced one-sided, sport-specific movement patterns.

Specific to the injury risk in adolescent hockey players, FMS TS results indicated that 60.7% of young skaters (13-16 years old) had total scores of 14 or less (Parenteau-G et al., 2014). Outcomes suggested that two out of three athletes were at an increased risk of suffering a non-contact injury or reoccurrence of a previous injury. However, research conducted in an adolescent population has found no relationship between scoring 14 or less and injury incidence (Bardenett et al. 2015; Aver et al., 2016).

Further to the sport of ice hockey, Boguszewski et al. (2017) compared FMS scores for hockey and non-hockey groups, in both males and females across two different

age groups (10-12 years old and 13-15 years old) and results suggested boys practicing hockey scored significantly higher than boys not playing hockey. Furthermore, for males only, in both practicing and non-practicing hockey groups, the older groups (13-15 years old) scored significantly higher on FMS TS, which may indicate higher level of functional fitness associated with growth and development. This study will expand on the current literature and explore the differences across hockey age groups and stages of maturity in male adolescent ice-hockey players.

The primary purpose of the current study was to compare FMS scores when analyzed by hockey specific chronological age groups versus stage of maturity. Chronological age has been traditionally used in the sport of hockey to define hockey-age groups. Atom players are 9-10 years, Pee wee players are 11-12 years, Bantam players are 13-14 years, and Midget players are 15-16 years. Stage of maturity calculated using the maturity offset equation (Mirward et al. 2002) defined the number of years away from the age of peak height velocity (APHV). The secondary purpose of the study was to determine if years of training in a unilateral sport, such as ice hockey, was significantly correlated with movement pattern asymmetries.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Functional Movement Screen (FMS)

The FMS has been used to assess movement inefficiencies and asymmetries in various populations (Kiesel, Plisky, & Voight, 2007; Parenteau-G et al., 2014). This assessment tool fills the gap between pre-participation screening and performance tests by evaluating individuals in a functional capacity (Cook, Burton, & Hoogenboom, 2006a). The screen consists of seven full body movement patterns that require varying degrees of muscular strength, stability, flexibility, coordination, and proprioception to execute with a level of proficiency. Each movement pattern requires the individual to maintain stability throughout a defined range of motion. The screen places the individual into positions where imbalances become noticeable if appropriate stability and mobility is not utilized (Cook, Burton, & Hoogenboom, 2006a).

The seven FMS movement patterns include deep squat (DS), hurdle step (HS), in-line lunge (ILL), shoulder mobility (SM), active straight leg raise (ASLR), trunk stability push-up (TSPU), and rotary stability (RS). In addition, three clearing exams (shoulder impingement, trunk flexion, and trunk extension) are performed immediately following the three affiliated movement patterns (SM, TSPU, and RS, respectively) to determine if pain is associated with execution of the movement. The FMS movements are scored using the criteria described by Cook, Burton, and Hoogenboom (2006b) with each movement scored on a scale from 0-3 points. A score of 3 is given for one repetition executed with no compensation, 2 is given for completion of a repetition with compensation, 1 is given for an inability to complete the movement, and 0 is given if pain was elicited during the movement (Cook, Burton, & Hoogenboom, 2006b). The clearing

exams are scored using ‘pain’ or ‘no pain’. If pain is associated with one of the clearing exams, a score of zero is given for the corresponding movement pattern.

A commercially available equipment kit has been developed to help guide the rater in properly administering the FMS movements and to enhance the reliability of the screen by providing the rater with standard starting positions for each screen and the correct compensations needed for deep squat (Appendix D). When the FMS is administered, individuals complete all seven movement patterns and TS out of 21 is calculated and interpreted as a measure of the quality of movement execution using objective criteria outlined in the FMS protocol designed by Cook, Burton and Hoogenboom (2006b). The FMS includes five bilateral movements (HS, ILL, SM, ASLR and RS) where both sides are scored independently with the lower score used for TS calculations. For example, if the left side scored a 2 and the right side scored a 3, an overall score of 2 will be used for the movement. Any difference in left/right scores is defined as an asymmetry.

In adults, a score of 14 or below has been proposed as an indication that there is a potential risk of injury for that individual (Teyhan et al., 2012; Kiesel et al., 2007). Although this cut off value has been questioned, it was initially derived from a study conducted on professional football players (Kiesel et al., 2007) which has the potential to limit generalizability across other populations. Other researchers have suggested that the cut-off score will likely change based on sport, age, skill-level, and maturity of the individual completing the assessment, suggesting challenges with using the FMS as a tool to predict injury (Wright et al. 2016). Furthermore, some studies have challenged and suggested differences in the interpretation of the cut off score. For instance, Dossa and

colleagues (2014) screened 20 hockey players (16-20 years old) and suggested using injury tracking from game one to game seventy six, over the course of one athletic season, scoring 14 or less did not put the athlete at a greater risk of injury.

Thus, the cut-off score of less than or equal to 14 is not supported consistently by the current literature (Dossa et al., 2014; Mokha, Sprague, & Gatens, 2016). Mokha, Sprague and Gatens (2016) argue that an analysis of the frequency of individual movement scores and/or frequency of asymmetries may allow for a more comprehensive interpretation of the FMS data in adult populations. A systematic review and a meta-analysis performed by Moran et al. (2017) concluded that the weak association between FMS total scores and subsequent injury does not support the use of FMS as an injury prediction tool.

Studies involving adult participants have also found no significant difference between male and female FMS total scores or the number of asymmetries (Kraus et al. 2014; Mitchell, Johnson, & Adamson, 2015) and no significant correlations between FMS total scores and athletic performance (Kraus et al. 2014; Parchmann & McBride, 2011). In an efficacy review by Kraus et al. (2014), it was determined that FMS can be safely administered to any population, sex, or age group as long as it is thoughtfully analyzed.

Professional sports leagues such as the National Hockey League (NHL) (Rowan et al., 2015) and National Football League (NFL) (Kiesel et al., 2007) have traditionally used the FMS as a pre-season evaluation tool at their respective draft events to determine if an athlete has any 'red flags' prior to training for the upcoming season (Cook, Burton,

& Hoogenboom, 2006a; Kiesel et al., 2007; Rowan et al., 2015). For example, consider a sport-specific movement pattern in the NFL for the position of an offensive lineman. If the lineman does not have enough stability or mobility to block functionally, the athlete may then be using compensatory movement patterns to overcome stability or mobility inefficiencies. This could include using their lower back, instead of their legs, as the driving force to hold off the attacker (Cook, Burton, & Hoogenboom, 2006a). This compensatory movement becomes heightened through training, practices, and competition, which could lead to further inefficiencies and possible injury or loss of playing time as a result (Cook, Burton, & Hoogenboom, 2006a).

The inter-rater and intra-rater reliability of the FMS screen has been evaluated in several populations including healthy adults, active duty service members, and young elite hockey players. It was found that inter-rater (between raters) reliability during real time administration of the FMS is moderate to excellent (intra-class correlation coefficient [ICC] = 0.89 & 0.87 (Teyhan et al., 2012; Smith et al., 2013; Parenteau-G et al., 2014). Minick and colleagues (2010) compared the results of 40 participants with 4 different raters: 2 experts and 2 novice raters. The results of the study showed that the FMS could be consistently scored by individuals with various experience levels after a 2-hour training session. Furthermore, the intra-rater (test re-test) reliability agreement scores at 48 and 72-hour intervals demonstrated strong agreement on DS, ASLR, TSPU, SM and IIL, moderate agreement on HS, but poor agreement on RS (Teyhan et al., 2012). Parenteau-G et al. (2014) screened 28 elite level male hockey players (13-16 years old) to determine the inter-rater and intra-rater reliability of the FMS. They found video raters demonstrated excellent intra-rater reliability (ICC =0.96) and, more importantly, field

raters achieved excellent inter-rater reliability for FMS TS, with an ICC of 0.96. Overall, studies have shown that physically active individuals screened in real-time using the FMS could be consistently scored by people with varying degrees of experience with the FMS (Smith et al., 2013; Schultz et al., 2013; Moran et al., 2016).

Research addressing the use of FMS in adolescent populations is somewhat limited, however several studies have been conducted recently. A study by Lloyd and colleagues (2015) explored the relationship between FMS scores, maturation, and physical performance in young male soccer players. Thirty young males within three age groups participated: athletes under 11 years old (U11), under 13 years old (U13) and under 16 years old (U16). Lloyd et al. (2015) found that the U16 participants were more physically mature (maturity calculated by age of peak height velocity equation), had higher FMS scores and outperformed the other two groups in the relative strength and reactive agility performance measures. While the U13 year-old participants were more physically mature than the U11 year-olds, they did not outperform them in any of the physical fitness tests (FMS, relative strength index, reactive agility) (Lloyd et al., 2015). This is significant because even though the U13 participants were more mature, increases in strength or improved performance were not revealed. Although this is a small sample size, this finding may suggest that younger males lack adequate strength to perform the FMS screens properly until after 13 years of age (or after peak height velocity) and FMS scores could possibly be affected by stage of maturity.

Portas and colleagues (2016) found differences when analyzing FMS total scores of ≥ 14 in 263 male English Football League soccer players (8-18 years old) who were divided into pre-peak height velocity (23.6 %) and post-peak height velocity (33.6%)

groups. As the participants became stronger, they tended to score better on an isolated screen (e.g., trunk-stability push-up) and as a result, increased their FMS total score. However, levels of muscular strength varied significantly in these youths, which could also affect FMS scores.

Although, the current research using FMS in adolescents has developed a base of knowledge, the working knowledge used to interpret the screen's results is limited by: (i) challenges in properly interpreting adolescents' FMS total scores (e.g. ≤ 14 points indicating injury risk may not be applicable to a younger population), (ii) limited control for maturity, and (iii) small sample sizes. It is suggested that FMS total scores in adolescents may be largely influenced by growth and development or may be more related to their stage of maturity as opposed to being representative of inefficient movement patterns and risk of injury (Lloyd et al. 2015). Therefore, understanding and interpreting FMS scores as a function of maturation, beyond age, in youth movement research is critical.

2.2 Measuring Growth and Development of Adolescents

It is widely recognized that measurements of maturity such as skeletal age, sexual maturity, and age of peak height velocity are correlated with chronological age. Chronological age is the most common way of grouping adolescents for comparison and is defined based on a calendar year that has astronomical rather than biological roots (Cameron, 2016). The term maturity refers to the level or the extent of a mature state an individual has progressed to (Malina, 2011). Individual maturation varies in time (maturity status at a given point), timing (when maturation events occur), and tempo (rate of maturation) (Malina, Bouchard, & Bar Or, 2004).

Alternatives to measuring growth and development solely by chronological age may consist of measures of peak height velocity, skeletal age, or sexual maturity. These measurements may be able to help identify whether different maturity statuses have similar movement patterns as assessed by the FMS screening tool. The literature contains significant evidence that inter-individual differences in physical maturity exist when children are grouped according to chronological age (Malina, Bouchard, & Bar Or, 2004). The following section describes methods used to quantify somatic maturity, skeletal age, and sexual maturity to determine which is best suited for this study. Reasons are given as to why they were excluded or included as a measure in the current study.

2.2.1 Skeletal Age (SA)

The most commonly cited method used to measure growth and development is the measure of skeletal age (SA). The signs of maturity based on skeletal development are evaluated by a radiologic examination of the hand (Schmidt, Nitz, Schulz, & Schmeling, 2008). The hand and wrist are placed flat with the palm facing down and fingers slightly apart on an X-ray plate (Malina, 2011). Changes in individual bones from initial ossification to mature state are quite uniform and provide the basis for assessing SA. Skeletal age has limited utility by itself but has meaning relative to chronological age (CA). To explain, Malina (2011) gives the following example:

A boy with a CA of 15.4 years may have a SA of 16.3 years; his SA is equivalent to that of a 16.3-year-old boy in a reference sample and is advanced in CA. Another boy may have a CA of 14.5 years but a SA of 13.0 years; the boy has the skeletal maturity equivalent to that of one with a CA of 13.0 years in the reference sample, and SA lags behind CA (pg. 927).

The two established methods for the determination of SA are the Greulich and Pyle (GP) and the Tanner and Whitehouse (TW).

The Greulich and Pyle method is also known as the atlas or inspectional method, and utilizes X-rays of the hand and wrist to compare and match the maturity pattern with standard X-rays of corresponding age and sex (Schmidt, Nitz, Schulz, & Schmeling, 2008).

The Tanner and Whitehouse (TW) method is sometimes called the bone-specific approach (Malina, Bouchard, & Bar Or, 2004). The method is based on matching the features of 20 individual bones on a given film to a series of specific, written criteria for the stages through which each bone passes in its progress from initial appearance to the mature stage (Malina, Bouchard, & Bar Or, 2004).

A systematic review completed by Malina in 2011, found that over the last 50 years, based on increasing age during adolescence, the number of later maturing male athletes has been declining while the number of early maturing athletes has been increasing. Furthermore, specific to ice-hockey players, Malina (2011) suggested that most peewee hockey players were on-time or late maturing whereas the bantam, midget, and junior age groups were on-time or early maturing (Table 1). The smallest difference between SA and CA appears to happen around the age of 17, suggesting that by this time, adolescents' skeletal development has caught up to their chronological age (Malina, 2011). Until that time, the variation in range of SA in a typical CA group can be up to four years (Malina, 2011).

In summary, SA assessment may be considered the best maturational index; however, it is costly and requires specialized equipment and trained interpretation of the

results to be deemed effective. Furthermore, there are radiation safety issues that would be a concern, especially in an adolescent population. Although the methodology covers the entire period of growth, it does not lend itself to fieldwork (Mirwald, Baxter-Jones, Bailey, & Beunen, 2001). For these reasons, skeletal age will not be used in this study.

2.2.2 Sexual Maturation

Sexual maturation generally occurs in an established sequence in both sexes; however, the age at onset and rate of sexual maturity vary for each individual and are influenced by genetics and environmental factors (Malina, 2011). Typically, sexual maturation is also associated with a growth spurt or other physical changes during which immature organs mature into adult form. Sexual maturation consists of a predictable series and order of development of secondary sexual characteristics and has been categorized into stages. For males, the “Tanner Stages” (Tanner, 1978) or pubertal stages are as follows:

Stage 1: Pre-pubertal

Stage 2: Enlargement of scrotum and testes

Stage 3: Enlargement of penis

Stage 4: Increased size in penis with growth in breadth and development of glans

Stage 5: Adult genitalia

Sexual maturity has been shown to be closely related to skeletal development and peak height velocity (Demirjian et al., 1985). However, the sexual maturity method of measurement has drawbacks, including privacy and cultural issues, and the fact that it is usually self-reported. Additionally, criteria of sexual maturity indicate stage of puberty at the time of observation. They do not tell you when that individual entered that specific

stage or how long the individual has been in that stage (Malina, 2011). Although sexual maturation could be considered an effective way to measure maturity, it will not be used for the purpose of this study due to the reasons outlined above.

2.2.3 Peak Height Velocity

Building on the different measures of maturity, somatic methods such as peak height velocity (PHV) have become popular as PHV is closely related to sexual maturity and skeletal maturity and its method of calculation is not expensive or invasive (Demirjian, Buschang, Tanguay, & Patterson, 1985; Mirwald, Baxter-Jones, Bailey & Beunen, 2002). Mirwald, Baxter-Jones, Bailey and Beunen (2002) developed a simple, nonintrusive method using only anthropometric measures to assess maturity status in children, known as age (\pm years) away from peak height velocity. Age of PHV (APHV) uses the known differential timings of changes in height, sitting height, and leg length and the relationship between them to provide an indication of maturational status (Mirwald, Baxter-Jones, Bailey & Beunen, 2001). Predicting APHV is completed by measuring anthropometrics from all subjects. Sex, date of birth, date of measurement, height, sitting height, and weight must all be collected to determine APHV (Mirwald et al., 2002).

The Saskatchewan Childhood Growth and Development (SCGD) research group has created an online version of this sex-specific multiple-regression equation that predicts how far an athlete is, in years, from hitting their PHV (Childhood Program Utility Programs, 2015). The recommended age range for males to use this program is 12-16 years as adolescent males typically hit their peak height velocity around 13-14 years old (Neinstein & Kaufman, 2002). While the equation will permit the input for

males from 9-18 years old, the accuracy of the equation is decreased the further away from 14-years-old the individual is in age.

Determining the years from the age of peak height velocity (APHV) allows one to group individuals into stages of maturity based upon how close an individual is to their maximum rate of growth. APHV is a crucial characteristic of the human growth curve as it marks an adolescent's growth spurt which, in turn, will allow us to form the maturity groups (Beunen et al., 2009). To quantify the timing of adolescent biological maturation, Beunen and colleagues (2009) used APHV to determine that boys tended to reach their APHV at 14 years of age and, typically, that is when the biggest within-group variability in maturation was found to occur compared to other chronological ages. Portas et al. (2016) used similar age categories (mid-youth development phase: Under 15, Under 14, Under 13) to investigate the effect of PHV on FMS scores and found athletes post-PHV scored higher on the FMS than athletes who were pre-PHV. This suggests that TS on the FMS may increase with development. APHV has also been used as a marker of training readiness to predict the best time to introduce strength training to adolescents, with the goal of helping to improve performance and training in youth at their biological age rather than their chronological age (Balyi, 2001). Given the opportunity provided, re-grouping participants by stage of maturity calculated by years away from age of peak height velocity will be used in the current study.

2.3 Strength Measures in Youth

Beyond physical development, muscular strength is also important to youth athletes and is defined as the ability of a group of muscles to maximally contract against a resistance in a single contraction (Wind et al., 2009). Muscle strength is an important part

of physical fitness as a decrease in muscular strength may cause functional limitations (Wind et al., 2009). As youth are still developing, it is essential to ensure the method used to obtain an accurate measurement of strength does not place extreme stress on the immature body.

Previous research in an athletic adolescent population has identified that strength is related to FMS total score. Research conducted by Portas et al. (2016) and Marques et al. (2017) has reported that younger athletes score poorly on the TSPU screen, resulting in low FMS total scores. Therefore, strength was assessed for all participants to determine the relationship between strength and FMS total scores.

Research has previously assessed adolescent strength through: standing long jump (SLJ), repetition maximum testing (1 RM), and grip strength (GS), all of which are considered practical, inexpensive, and relatively safe for adolescents (Wind et al., 2009; Castro-Pinero et al. 2010; Faigenbaum, Milliken, & Westcott, 2003). For this study, GS will be used to measure adolescent strength. The standing long jump (SLJ) and repetition maximum testing (1 RM) are valid options for measuring adolescent strength, and were considered for this study, but they were not selected due to their limitations as described below.

The standing long jump (SLJ), also referred to as broad jump, is performed to assess muscular strength and power. The adolescent is asked to stand at the take-off line and jump as far forward as possible to complete this activity. The SLJ measures the distance, in centimeters, from the starting line to the back of the heel of the participant nearest to the take-off line. Subjects are typically tested twice, and the best score is retained (Castro-Pinero et al., 2010). The SLJ is commonly used because it is cost

effective, easy to perform, and can relate to upper and lower body strength (Castro-Pinero et al. 2010). Castro-Pinero and colleagues (2010) found that lower-body explosive muscular strength tests had a strong association with each other and moderate association with upper-body strength tests. Association between SLJ and the lower-body strength test was $R^2 = 0.829-0.864$ and upper-body strength tests was $R^2 = 0.694-0.851$. The SLJ is easy to perform, feasible, has been used in both epidemiological studies and school settings (Castro-Pinero et al. 2010), however, it is best suited to determine muscular power, not strength, making it inappropriate for the current study.

Faigenbaum, Milliken and Westcott (2003) studied children from 6-12 years old and found no abnormal responses to, or injury from, 1 RM testing suggesting that maximum force production can be measured using 1 RM testing in children. However, reports have stated some damage to epiphyses or growth cartilage in adolescents who are strength training with heavy loads (Faigenbaum, Milliken, & Westcott, 2003). That said, although it is accepted that 1 RM is the standard for measuring muscular strength, it is not practical for data collection because of limitations for field tests. Milliken et al., (2008) concluded while 1RM strength testing can be used to assess muscular strength in children, it is a labor-intensive process requiring close supervision.

The grip strength test was selected as the preferred measurement for this study due to the limitations of the other two measurement options and the strengths of this assessment. Grip strength is a feasible and effective field-test that has been shown to have a strong correlation with overall muscle strength in both adults and children (Wind et al., 2009). Grip strength is measured bilaterally in a standing position, arms at the side not touching the body, with the elbow bent slightly. The handheld dynamometer can be

adjusted to fit the participant's hand and strength is measured in kilograms. To perform the grip strength assessment, participants are encouraged to squeeze the handheld dynamometer as hard as possible for five seconds. Measurements are performed three times, with a minimum 10-20 second break in between maximal repetitions, and the highest value is used for analysis (Wind et al., 2009). Grip strength scores tend to vary between left and right hands (L/R dominance).

Many studies have reported a significant association between GS and physical fitness, however, there are some inaccuracies on an individual level (Wind et al., 2009). Wind and colleagues (2009) found that GS and total muscle strength (the summing of shoulder abductors, hip flexors, and ankle dorsi-flexors) in adolescents was strongly correlated. The correlation became moderate after adjusting for weight. Tremblay and colleagues (2009) studied GS in 2,087 children aged 6-19 years old in a Canada Health Measures Survey and found that males were stronger than females and that GS scores increased as age increased. Despite the differences that occur based on weight and age, GS will be used in the current study to represent overall muscle strength because of its feasibility, effectiveness, and its ability to be performed in a safe and timely manner.

2.4 Flexibility Measures in Youth

As the adolescent growth spurt occurs, and the relationship between flexibility and growth is somewhat unclear. Feldman et al. (1999) found that there was no relation between growth and changes in flexibility for lumbar flexor muscles, hamstring muscles or muscles involved in the Sit and Reach test. However, they did find a slight decrease in quadriceps muscle flexibility.

The gold standard measure for flexibility is the use of a goniometer to measure the range of motion (in degrees) at any given joint. Although this device can be used in various joint angles, it comes with significant limitations including; it is difficult to position and maintain the arms of the goniometer along the bones of the segments throughout the measurement, and the axis of rotation is not always clear, especially for complex joints. For the purpose of this study, flexibility was assessed using the standardized Sit and Reach protocol published by Wells and Dillon (1952). The Sit and Reach test is generally considered an acceptable field test to measure hamstring flexibility for most age groups (Baltaci et al. 2002). The most common assumption when interpreting Sit and Reach results is that participants with higher scores possess an increased degree of trunk and hip flexibility than those with a lower score. Although, flexibility does not appear to change with growth and development, we thought it would be important to compare Sit and Reach scores to the Functional Movement Screen scores. Therefore, the Sit and Reach scores were compared to FMS total score and FMS frequencies of asymmetries to determine if a relationship exists between flexibility of FMS scores.

2.5 Summary of Review of Literature

While extensive research using the FMS on mature athletes has been published (Chapman et al., 2014; Teyhan et al., 2012; Kiesel et al., 2007; Yongming, Xiong, Xiaoping, & Boyi, 2015; Smith et al., 2013; Rowan et al., 2015), only a few studies have used FMS to screen an athletic adolescent population (Mitchell, Johnson, & Adamson, 2015; Lloyd et al., 2015; Parenteau-G et al., 2014; Portas et al., 2016). Given that maturity throughout a birth-year can range widely within a group of adolescents,

measuring FMS in individuals with the same chronological age can produce varying results. Each individual's timing and tempo of maturation varies which means adolescents have unique biological ages (Malina, Bouchard & Bar Or, 2004), with variations in strength, power, and limb length increases. Furthermore, adolescents have different experiences, such as playing another competitive sport or variation in years of elite level sports experience, which could produce different movement patterns. Individuals who mature early may have greater strength, power, and performance advantages. As a result, it is also important to consider stages of maturity in addition to chronological age alone when using FMS in adolescent populations.

2.6 Purpose

The primary purpose of the study was to compare FMS scores when analyzed by chronological age versus stage of maturity in adolescent male ice-hockey players. Chronological age is used in the sport of hockey to define hockey-age groups: Atom players are 9-10 years old, Pee wee players are 11-12 years old, Bantam players are 13-14 years old, and Midget players are 15-16 years old. Stage of maturity was calculated using the maturity offset equation (Mirward et al. 2002) and is defined as years away from peak height velocity (APHV). The secondary purpose of the study was to determine if years of training in a unilateral sport such as ice hockey was positively correlated with movement pattern asymmetries.

2.7 Research Questions

The four research questions are:

1. Was there a significant difference in mean FMS total score (out of 21) across the four hockey age groups (Atom, Pee wee, Bantam, and Midget) in male AAA hockey players?

- 2.. Was there a significant difference in mean FMS total score (out of 21) across the five stages of maturity (<-2 APHV, Between -2 & -1 APHV, ± 1 APHV, Between $+1$ & $+2$ APHV, $+2$ APHV) in male AAA hockey players?
3. Does physical maturity contribute to FMS total score (out of 21) beyond the effect of age in male AAA hockey players?
4. Is there a relationship between FMS TS, FMS frequencies of left/right asymmetries and total years of hockey participation?

2.8 Significance of Study

Outcomes of the study have the potential to: (i) provide insight into the interpretation of FMS scores relative to both chronological age and stage of maturation in male adolescent ice-hockey players, (ii) provide further understanding of how to interpret FMS results in adolescents, (iii) identify the influence of sport-specific training on movement asymmetries, and (iv) educate athletes, coaches, and trainers on evaluating movement efficiencies.

CHAPTER 3: METHODOLOGY

3.1 Study Design

The study was conducted using a cross-sectional design. A letter of introduction (Appendix A) detailing the study, consent/assent forms (Appendix B), and a hockey experience questionnaire (Appendix C) were emailed to all participants in advance of scheduling the physical data collection. Data were collected during the competitive hockey season and consistently following an on-ice practice for all participants. Physical assessments included: anthropometric measures [height (cm), sitting height (cm), and weight (kg)], a measure of strength [grip strength (kg)], a measure of flexibility [sit and reach test (cm)] and the Functional Movement Screen (FMS) (Appendix D).

3.2 Hockey Experience Questionnaire

The hockey experience questionnaire (Appendix C) was developed for the purpose of the study to profile the sport specific experience (i.e., years, level, etc.) of all participants. Specifically, the questionnaire profiled how long the athletes have played competitive ice hockey (in years), how long the athletes have played AAA ice hockey (in years), left/right hand dominance, left/right sport dominance, if the athlete played another competitive sport, and if the athlete self-reported as injury free. Participants completed this questionnaire with their parents in the privacy of their own home and submitted responses to the researcher by email or in person at the time scheduled for physical data collection.

3.3 Participants

One hundred and eleven (N=111) male competitive (AAA) ice-hockey players representing four hockey age categories (Atom n=29, Peewee n=25, Bantam n=31, Midget n=25) were recruited to participate. Participants were recruited through the On-Ice Performance Laboratory at Brock University as it has a well-established network of local players, coaches, and teams interested in participating in research. Inclusion criteria mandated that participants were actively playing AAA ice hockey during the 2018-2019 season and self-identified as injury free. The study limited recruitment to males due to the differing maturation rates between boys and girls.

The study obtained ethics clearance from Brock University's Research Ethics Board (File #17-130) and both participant consent and parental assent were obtained prior to conducting the research.

3.4 Physical Measures

Assessments included: anthropometric measures [height (cm), sitting height (cm), and weight (kg)], a measure of strength [grip strength (kg)], a measure of flexibility [sit and reach test (cm)] and the Functional Movement Screen (FMS) (Appendix D). The following provides a detailed description of the protocols used for the physical assessments. Participants were screened individually in a circuit-like station format whereby each participant rotated from one station to the next.

3.4.1 Anthropometric Measures

The anthropometric measurements were completed as follows:

1. Standing height measured without shoes using wall mounted measuring tapes (34-106 Long Tape Measure, Stanley Black & Decker, New Britain, CT) measured in centimeters to the nearest half centimeter.
2. Sitting height (on the floor, legs straight out) using wall mounted measuring tapes (34-106 Long Tape Measure, Stanley Black & Decker, New Britain, CT) measured in centimeters to the nearest half centimeter.
3. Weight measured without shoes using a digital scale (WSI- 600, Mettler Toledo, WeighSouth INC, Asheville, NC) measured in kilograms to the nearest tenth of a kilogram.

3.4.2. Strength

Strength was assessed using the grip strength protocol published by Fess and Moran (1981). Participants were in a standing position with the shoulder adducted and elbow tucked in and flexed slightly, but not touching the body. The handheld dynamometer was adjusted to fit each participant's hand and strength was measured in kilograms. To perform the grip strength assessment, the participants were measured bilaterally and were encouraged to squeeze the handheld dynamometer to maximal exertion for 5 seconds, alternating hands between repetitions. Measurements were performed three times on each side with a 15 second minimum break in between maximal reps. The highest scores for the left and right sides were summed and recorded for the purpose of analysis.

3.4.3. Flexibility

Flexibility was assessed using the standardized sit and reach protocol published by Wells and Dillon (1952). Participants were seated on the floor with both legs fully

extended, shoulder width apart, and feet (without shoes) placed flat against a box. With one hand on top of the other and the knees fully extended, the participants slowly reached forward (without jerking) as far as possible, sliding their hands across the top of the ruler, and holding the final position for at least two seconds. The score, in centimeters, was recorded as the final position of the fingertips on or towards the ruler. The test was performed twice and the highest score (to the nearest centimeter) was used for data analysis.

3.4.4 Functional Movement Screen Protocol

FMS consists of a series of seven movements, including: deep squat (DS), hurdle step (HS), in-line lunge (ILL), shoulder mobility (SM), active straight leg raise (ASLR), trunk stability push-up (TSPU), and rotary stability (RS). Participants were briefed on the purpose of conducting the FMS and its procedures as detailed in Appendix D & E. A visual demonstration of each movement was provided to ensure each participant understood the movement patterns. The FMS movement criteria and scoring protocol as described by Cook, Burton, and Hoogenboom (2006a) were used. All movements were scored on a scale of 0 through 3; a score of 3 points was given for a repetition with no compensation, 2 points was assigned for completion of a repetition with compensation, 1 point was assigned for the inability to complete the movement, and a score of 0 was assigned if pain was elicited during the movement (Cook, Burton, & Hoogenboom, 2006b). Subjects were given three attempts to complete the movement to the best of their ability and the highest score was recorded. For the bilateral movements (HS, ILL, SM, ASLR and RS), both left and right sides were scored independently, and the lower score was used for total score calculations (i.e., if the left side scored a 2 and the right side

scored a 3, an overall score of 2 was recorded). Three post-screening clearing tests corresponding to three of the initial seven movement screens, shoulder impingement (SM), trunk flexion (TSPU) and trunk extension (RS) were conducted to identify the presence of pain, following the FMS guidelines.

Specific to this study, the lead researcher provided a two-hour workshop for the research assistants on the protocol and procedures of the FMS to ensure adequate training of the raters. The workshop included a detailed explanation of all seven movement screens, the three clearing exams, the verbal instructions, and the scoring criteria developed by Cook, Burton and Hoogenboom (2006a). This workshop style is consistent with the research conducted by Smith and colleagues (2013) that resulted in good inter-rater reliability (intra-class correlation coefficient [ICC] = 0.89 & 0.87).

3.4.5 Peak Height Velocity and Maturity Offset

Stage of maturation was determined using the years from age of peak height velocity (APHV) as described by Mirward and colleagues (2002). APHV was defined as the \pm years away from peak height velocity (PHV) calculated by the maturity offset equation detailed below.

Maturity Offset =

$$\begin{aligned}
 & - [9.236 + 0.0002708 * \text{leg length (cm) and sitting height (cm)}] \\
 & - [0.001663 * \text{age (yrs) and leg length (cm)}] \\
 & + [0.007216 * \text{age (yrs) and sitting height (cm)}] \\
 & + [0.02292 * \text{weight (kg) by height (m) ratio}]
 \end{aligned}$$

Results of the maturity-offset equation calculations were used to categorize subjects into the five maturity phases (Table 2).

3.5 Statistical Analysis

Statistical Package for the Social Sciences (SPSS) software, version 25 (IBM, Chicago, IL) was used for all statistical analyses. Descriptive statistics, including mean (M) and standard deviation (SD), were calculated for all variables. All participant responses to the hockey experience questionnaire were analyzed to profile previous hockey experience and other sport participation. A Pearson product-moment correlation was used to identify the relationship between age (birth month) and maturity. Further, a Pearson product-moment correlation was used to identify the relationship between years of playing hockey and years of playing AAA hockey.

The PHV maturity offset equation was used to regroup the participants by stage of maturity (Mirwald et al., 2002). Table 3 detailed the redistribution of participants from four hockey-specific chronological age categories into the five stages of maturity. All further analyses were conducted using the two methods of grouping participants (hockey age groups and stages of maturity).

Grip strength (kg) scores were calculated by summing the left and right highest score. One-way ANOVA was used to investigate the differences in grip strength across groups. Further, grip strength scores were divided by body weight (kg) to determine a relative strength measure for all participants. Correlations were used to determine the relationship between relative strength and FMS TS. A Pearson product correlation coefficient (r) calculations was used to identify the relationship between FMS_{stab} and grip strength scores.

Sit and Reach score (cm) was calculated by taking the participant's best score. Further, sit and reach scores were used as a flexibility measure. A One-way ANOVA was

used to investigate the differences in sit and reach scores across groups. Correlations were used to determine the relationship between flexibility and FMS TS. A Pearson product correlation coefficient (r) calculations was used to identify the relationship between FMS_{flex} and sit and reach scores.

A Pearson partial correlation coefficient (r) calculations were used to identify relationships between total FMS scores, FMS frequencies of asymmetries, years of elite level (AAA) experience and years of hockey experience with age being the covariate.

FMS total score (FMS TS) was calculated by summing the scores of the seven screens for each individual. A one-way analysis of variance (ANOVA) was conducted to examine the differences in FMS TS across four hockey age groups and across five stages of maturity.

Bonferroni post-hoc significance tests were performed to determine where the significant differences were located ($p \leq .05$). A one-way analysis of covariance (ANCOVA) was conducted to examine the differences in FMS TS across the four hockey age groups with maturity entered as the covariate.

To provide a deeper understanding of whether there were specific individual movement patterns that dominated differences in FMS TS, the individual movement screens were grouped into three sub groups: FMS_{move} (3 movement tests; DS, HS, ILL); FMS_{flex} (2 mobility tests; SM and ASLR), 2 FMS_{stab} (2 stability tests; TSPU and RS) (Portas et al., 2016). Multiple one-way ANOVA were conducted to identify significant differences in FMS_{move}, FMS_{flex} and FMS_{stab} across the four hockey age groups and five stages of maturation. Bonferroni post-hoc significance tests were performed to determine where the significant differences were located ($p \leq .05$).

Left and right asymmetries were quantified for the five bilateral movement patterns.

A Pearson chi-square test for association was conducted to identify significant differences in frequency of asymmetries across the four hockey age groups and across the five stages of maturity. Phi and Cramer's V tests were used to identify the strength of association between the variables.

Frequencies of scores of 1, 2, and 3 were also analyzed across the four hockey-age groups and by the five stages of maturation. An alpha level of $p \leq .05$ was used for all analyses.

CHAPTER 4: RESULTS

4.1. Participant Descriptives

One hundred and eleven (N=111) male competitive (AAA) ice-hockey players representing four hockey age groups (Atom n=29, Peewee n=25, Bantam n=31, Midget n=25) were recruited to participate. Participant descriptives including age (birth year), weight (kg), height (cm), and sitting height (cm) were collected and means \pm standard deviations are detailed in Table 3. Table 4 profiles years of hockey experience, years of AAA experience, and participation in other competitive sports. Sport dominant hand was determined by the bottom hand on the hockey stick (left/right handed); data revealed that 34/111 (30%) of participants were right hand dominant. Alternatively, handedness referred to which hand the athlete writes with, and 102/111 (92%) participants identified as right-handed. Furthermore, many participants 69/111 (61.2%) played another competitive sport at a travel or elite level; the most commonly played secondary sport was soccer at 37/111 (33.3 %) (Table 4).

A maturity equation was used to regroup participants from hockey age to stage of maturity (Mirwald et al., 2002). Table 3 illustrates the distribution across the four hockey age specific categories versus the five stages of maturity defined as their APHV. Figure 1 provides a visual of Table 3, illustrating the same distribution. All further analyses were conducted using both methods of grouping participants (hockey age groups and stages of maturity).

A Pearson product-moment correlation identified a significant, strong correlation between age (birth month) and maturity (\pm years from PHV) ($r = .967$, $n = 111$), $p < .001$. It was also determined that hockey age group and stage of maturation had a significant

strong positive correlation ($r = .918$, $n = 111$), $p < .001$. Further, a Pearson product-moment correlation identified a strong, positive relationship between years of playing hockey and years of playing AAA hockey ($r = .712$, $n = 111$), $p < 0.001$, suggesting that participants who played hockey longer were also more likely to play more years in AAA hockey.

Height (cm), sitting height (cm) and weight (kg) significantly increased across both hockey age group and stage of maturity ($F(3,107) = 132.5$), $p < .001$). One-way ANOVA's were used to investigate the differences in grip strength and sit and reach independently across groups. Grip strength significantly increased across all hockey age groups ($F(3,107) = 79.434$), $p < 0.01$ and increased significantly across all stages of maturity ($F(4,106) = 55.067$), $p < 0.01$. A Bonferroni post-hoc test determined that each group was significantly different from the others. Mean and SD values for grip strength and sit and reach for all four hockey age groups and five stages of maturity are displayed in Figures 3, 4, 5, and 6. Figures 3 and 4 illustrate the relationship between grip strength for hockey age group as well as stage of maturity.

Similarly, sit and reach scores were significantly different across hockey age groups ($F(3,107) = 7.756$), $p < .001$. A Bonferroni post-hoc test revealed that Midget age players (32.7 ± 8.8) scored significantly higher than Atom (25.6 ± 5.8), $p < 0.001$, Peewee (24.6 ± 4.6), $p < 0.001$, and Bantam players (26.7 ± 6.8), $p = 0.004$. Significant differences in sit and reach were also found across the stages of maturity ($F(4,106) = 6.008$), $p < .001$. A Bonferroni post-hoc test revealed that maturity stage 5 (35.8 ± 8.4) participants scored significantly higher than maturity stage 1 (25.9 ± 5.3), $p = .001$, maturity stage 2 (24.4 ± 6.1), $p < .001$, and maturity stage 3 (27.4 ± 6.4), $p = .008$. This

suggests that Midget players and the corresponding maturity stage 5 players had greater flexibility in their hamstrings and lower back than players in the younger chronological age groups and maturity stages. Figures 5 and 6 illustrate the significant increase in sit and reach scores across the four hockey age groups and the five stages of maturity.

4.3 Functional Movement Screen Scores

The FMS movement scores were analyzed by: (i) FMS total score, (ii) sub groups of movement screens into FMS_{move} , FMS_{flex} , FMS_{stab} , (iii) the frequencies of individual movement scores (1, 2, 3's), and (iv) frequency of asymmetries. Total score is the sum of the seven individual movement screens scored on a scale from 0-3 for a potential of 21 points. Grouping the seven FMS movements into three categories (FMS_{move} , FMS_{flex} and FMS_{stab}) allows for a deeper understanding of what the individual movements patterns revealed. FMS_{move} is a sub-score of three movement tests including DS, HS, and ILL. FMS_{flex} is a sub-score of two mobility tests: SM and ASLR. FMS_{stab} is a sub-score of two stability tests: TSPU and RS (Portas et al., 2016, Marques et al., 2017).

Frequency of individual movement scores (1, 2, 3's) were examined to identify whether specific movements were related to FMS total scores and if any trends could be identified with further analysis of individual movement scores. Frequencies of asymmetries were used to identify whether maturity or playing elite level ice-hockey posed a risk for potential injury. All FMS scores as outlined above were analyzed by hockey age groups and stages of maturation.

4.3.1 FMS Total Score

A one-way ANOVA revealed statistically significant differences in FMS total scores across hockey age groups (Table 5, $F(3,107) = 7.002$), $p < .001$. A Bonferroni post-

hoc test revealed that Midget players (16.73 ± 1.64) scored significantly higher than both Atom players (14.62 ± 2.31), $p < 0.001$ and Peewee players (15.12 ± 1.59), $p = 0.011$ players. No other significant pairwise differences were found. In adults, a score of 14 or below has been proposed by some researchers as an indicator of potential injury risk (Teyhan et al., 2012; Kiesel et al., 2007). In the current study, 14% of the participants had an FMS total score of less than or equal to 14 points (34% of Atom, 16% of Peewee, 7% of Bantam and 0% of Midget players)

A one-way ANOVA revealed statistically significant differences in FMS total scores across the five stages of maturity (Table 8, $F(4,106) = 4.790$), $p < .001$. A Bonferroni post-hoc test revealed that maturity stage 5 players (17.00 ± 1.84) scored significantly higher than both maturity stage 1 players (14.98 ± 2.19), $p = 0.015$ and maturity stage 2 players (14.82 ± 1.47), $p = 0.026$. Further, a statistically significant difference was also found between maturity stage 4 players (16.64 ± 1.45) and maturity stage 1 players (14.98 ± 2.19), $p = 0.039$. No other significant pairwise differences were found.

A one-way ANCOVA revealed no significant difference across hockey age groups ($F(3,106) = 1.917$), $p = .131$, when maturity was entered as a covariate, suggesting that maturity does not influence FMS TS beyond age.

4.3.2 FMS move, flex, stab

A one-way ANOVA revealed a statistically significant difference in FMS_{move} across the four hockey age groups ($F(3,107) = 3.684$), $p = 0.014$. A Bonferroni post-hoc test revealed that Peewee players ($6.28 \pm .995$) scored significantly lower than Midget players ($7.23 \pm .908$), $p = 0.015$. No other between group differences were significant.

There were no statistically significant differences in FMS_{move} scores across the five maturity stages ($F(4,106) = 1.852$), $p = .124$. Tables 5 and 6 provide the FMS_{move} scores where it appears that Pee wee players scored lower than all other hockey age groups. However, that decrease in scores does not appear on the stages of maturation graph, which could be related to the relatively equal distribution of Pee wee players between stage 1 and stage 2 of maturity.

A one-way ANOVA revealed no statistically significant differences in FMS_{flex} scores across the four hockey age groups ($F(3,107) = 1.320$), $p = .272$. There were also no statistically significant differences in FMS_{flex} across the five maturity stages screen scores ($F(4,106) = 0.700$), $p = .594$. A Pearson product-moment correlation found a weak, positive correlation for the relationship between the sit and reach test and FMS_{flex} ($r = .283$, $n = 111$), $p = .003$. A similar trend can be visually seen in Tables 5 and 6 related to the FMS_{flex} scores between the hockey age groups and stages of maturity.

A one-way ANOVA revealed a statistically significant difference in FMS_{stab} scores across the four hockey age groups ($F(3,107) = 13.984$), $p < .001$. A Bonferroni post-hoc test revealed that Midget players ($4.69 \pm .618$) scored significantly higher than all three other age groups: Bantam ($4.13 \pm .885$), $p = .039$, Pee wee ($3.88 \pm .726$), $p < .001$, and Atom ($3.38 \pm .775$), $p < .001$. It was also determined that Bantam players ($4.13 \pm .885$) scored significantly higher than Atom players ($3.38 \pm .775$), $p < .001$. No other between group differences were significant. Lastly, a significant difference in FMS_{stab} scores across the five stages of maturity was found ($F(4,106) = 8.572$), $p = .001$. A Bonferroni post-hoc test revealed that maturity stage 5 ($4.73 \pm .786$) was significantly higher than maturity stage 2 ($3.82 \pm .728$), $p = .037$ and maturity stage 1 ($3.61 \pm .891$), $p =$

.001. Furthermore, maturity stage 4 ($4.78 \pm .426$) was significantly higher than maturity stage 3 ($4.04 \pm .793$), $p = 0.044$, maturity stage 2 ($3.82 \pm .728$), $p < .001$, and maturity stage 1 ($3.61 \pm .891$), $p < .001$. A Pearson product-moment correlation revealed a moderate, positive correlation between grip strength and FMS_{stab} ($r = .412$, $n = 111$, $p = .001$). When comparing the FMS_{stab} scores in Tables 5 and 6, similar findings emerged in both hockey age groups and stage of maturity as a post hoc analysis revealed higher scores for Midget and stage 5 compared to Atom and Pee wee and maturity stage 1 and 2, respectively.

4.3.3. FMS Frequency of Individual Screen Scores

Frequencies of individual screen scores are illustrated in Tables 9 and 10. Seventy-seven percent of participants scored a 1 on one or more of the individual movement screens (100% of Atom, 80 % of Pee wee, 58% of Bantam, 23% of Midget). When analyzing frequencies of scores (1, 2, and 3's) across the four hockey age groups, the greatest difference in frequency of scores was seen in the TSPU. Fifteen (51.7%) Atom participants scored a 1, 8 (32%) Pee wee players scored a 1, 9 (29%) Bantam players scored a 1. However, for Midget players, only 1 (3%) participant scored a 1. Furthermore, RS had the lowest number of 1's ($n=5$). Trunk stability push-up had the greatest frequency of 1 scores with 33 participants unable to complete the movement.

When analyzing frequencies of individual movement scores across stage of maturity (Table 10), the data suggest that after the participants reach age of peak height velocity (roughly 14 years old), their TSPU scores increased. When maturity stages 4 and 5 (post PHV) were combined, only one participant scored a 1 (4%) on TSPU while 8 (29%) participants in maturity stage 3 scored a 1. When pre-PHV stages (maturity stage 1

and 2) were combined, 24 (41%) participants scored 1 on TSPU, meaning TSPU had the biggest variation in frequency of scores as age increased. Scores of 1 on ILL (17%) and DS (20%) were also more frequent in maturation stage 1 than the rest of the stages.

4.3.4 FMS Frequencies of Asymmetries

Descriptive analysis of the frequencies of asymmetries is reported in Tables 9 and 10. Asymmetries were defined by counting the number of movement screen scores that revealed left/right differences. Results revealed 44% of participants had an asymmetry. The HS showed the highest number of asymmetries for all participants ($n = 28$, 25.2%) while RS had the lowest number of asymmetries ($n = 3$, 2.7%). Frequency of asymmetries by hockey age group revealed that Bantams had the highest percentage (51.6%) of one or more asymmetries. The highest percentage of athletes to have an asymmetry on one particular screen was the Bantam players on ILL with 11 out of 31 (35.5%) having a asymmetry identified.

Frequency of asymmetries by stage of maturity revealed that maturity stage 1 had the greatest frequency of asymmetries with 28 athletes identifying an asymmetry (68.3%). This was not surprising as maturity stage one was the largest. However, maturity stage 2 had the greatest percent of athletes identifying an asymmetry with 100% of participants. Maturity Stage 5 had the lowest frequency and percentage of asymmetries (63.6%).

Although not significant, the main difference between hockey age group and stage of maturity was found in the results of the HS screen. An analysis of frequencies of asymmetries on the HS screen revealed that maturity stage 1 had 12 (29.5%) participants

with an asymmetry, however, only eight Atoms identified an asymmetry on HS, meaning four less mature Peewee's also identified an asymmetry.

A Chi-square test for association determined that there were no significant differences in frequencies of left/right asymmetries across the four hockey age groups, furthermore, a second Chi-square test for association also determined that there were no significant differences in frequencies of left/right asymmetries across the five stages of maturity.

4.4 Relationship between FMS Scores and Years of Hockey Participation

A Pearson product moment correlation was completed to explore the relationship between FMS TS and years of playing AAA hockey. There was a significant yet weak, positive correlation between years of playing AAA hockey and FMS TS ($r = .324$, $n = 110$), $p = 0.01$. For this analysis, one outlier was removed as the participant had a perfect score. A partial correlation was completed to explore the relationship between FMS TS and years of playing AAA hockey with age being the covariate. No significant correlation was found. Another partial Pearson product moment correlation was run to explore the relationship between years of playing AAA hockey and frequencies of asymmetries with age being the covariate. No significant correlation was found between frequencies of asymmetries and years of playing AAA hockey ($r = -.061$, $n = 111$, $p = .525$).

4.5 Relationship between FMS Scores and Playing Competitive Sport

In addition to their participation in the sport of hockey, 83 out of 111 participants (74%) played another competitive sport (Table 4). The sport participation questionnaire revealed that this cohort also played soccer (33%), lacrosse (20 %) or baseball (17%). To

our knowledge, no other functional movement screen studies in adolescents have discussed the participation in other recreational or competitive sports.

Peewee athletes had the highest participation in other competitive sports (92%), while Atom (83%), Bantam (61%) and Midget (65%) players participated in another competitive sport. Bantam hockey players had the lowest participation percentages in another competitive sport at an elite or travel level (45%) while Midget (61%), Atom (69%), and Peewee players (76%) were more likely to participate in elite or travel competitive sport.

An independent t-test revealed no significant differences in FMS TS, whether playing another competitive sport or not $t(108)=-.540, p=.590$.

CHAPTER 5: DISCUSSION

The primary purpose of the study was to compare FMS scores across four hockey-specific chronological age groups and five stages of maturity in adolescent male ice-hockey players. The secondary purpose of the study was to determine if years of experience in a specific sport, correlated with movement pattern asymmetries. Ice-hockey participation was used as a vehicle to access and study a cohort of athletic adolescents that were categorized by both age and ability. One hundred and eleven male, AAA ice-hockey players were recruited to participate. Participants represented four hockey age categories (Atom n=29; Pee wee n=25; Bantam n=31; Midget n=25) and five stages of maturity (>-2 yrs away from PHV n=40; between -2 and -1 yrs n=15; between -1 and +1 yrs n=29; between +1 and +2 yrs n= 14; >+2 yrs. away from PHV n=11). It was hypothesized that FMS total score would increase with both hockey age and stage of maturity, whereby, chronologically older and more physically mature athletes would achieve higher FMS TS scores. It was also hypothesized that frequencies of left/right asymmetries would increase with years of exposure to competitive ice hockey.

As was expected in this cohort, height and weight increased significantly across both hockey age groups and stage of maturity. More specifically, within an 8-year span (2002-2009 birth years), weight ranged from 24kg to 85kg and height ranged from 128cm to 189cm. In term of descriptive characteristics and sample size, our study is similar to other studies involving elite level hockey players within the adolescent age range (Parenteau-G et al., 2014; Boguszewski et al., 2017).

Many youth sports use chronological age as a method of grouping or categorizing participants. In the current study, participants recruited by hockey age were also

regrouped into one of five stages of maturity. The distribution of the four hockey age groups to the five stage of maturity resulted in the following: Atom players were identified as maturity stage 1, Pee wee players were distributed relatively evenly across maturity stage 1 (n=11) and maturity stage 2 (n=14), Bantam players were primarily maturity stage 3 (n=26), however there were two athletes categorized as maturity stage 2 and two athletes categorized as maturity stage 4, and Midget players were the most diverse, distributed across maturity stage 3 (n=3), maturity stage 4 (n=14) and maturity stage 5 (n=11). To our knowledge, no FMS study has regrouped their adolescent participants based upon maturity to compare both physical maturity and chronological age for the purpose of FMS analysis. Unlike chronological age, which is calculative and predictable, stage of maturity or rate of development is more variable and therefore, the distribution becomes complicated.

Physical measures including strength (measured by grip strength) and flexibility (measured by the sit and reach) were collected to provide a reference for further interpretation of the FMS scores. As expected, grip strength measurements significantly increased across both hockey age group and stage of maturity. Unlike grip strength, sit and reach did not reveal the same trend. Midget players or those regrouped into maturity stage 5 scored significantly higher on the sit and reach test in comparison to the other groups. A possible explanation might be that the older, more experienced athletes have adopted training programs to develop hamstring and lower back flexibility to improve their sport performance. Grip strength and sit and reach scores will be referenced further in comparison with the FMS individual movement pattern scores.

The current study adopted and implemented the standardized FMS protocol (Cook, Burton, & Hoogenboom, 2006a). Traditionally, the analysis and interpretation of FMS scores focuses on the total score, which is a sum of the individual movement screens out of a potential 21 points. In an adult population, a total score of ≤ 14 points is commonly considered the threshold below which an individual is at a potential risk for injury (Kiesel et al., 2007). However, more recently, Wright et al. (2016) suggested that the threshold, or what is often referred to as a cut-off score, is likely to be affected by sex, maturity level, sport participation and/or skill level. In an adolescent population, Bardenett et al., (2015) found no differences in FMS TS with or without injury and argued that they were unable to create a new potential cut-off score for injury risk in adolescent populations. The cut-off score of 14 or less was used to compare our athletes to other similar studies, as the current study did not track injury.

In the current study, only 14% of the participants scored 14 points or less. That said, the mean score for each hockey age group was slightly above the threshold (Atom = 14.6 ± 2.3 , Peewee = 15.1 ± 1.5 , Bantam = 15.8 ± 1.6 and Midget = 16.7 ± 1.6). These findings are inconsistent with the current literature comparing FMS scores in adolescent populations. Marques et al. (2017) found 82% of their athletes had a total score of 14 points or less and Parenteau-G et al. (2014) identified that 60.7% of their adolescent hockey players had a total score of 14 points or less. In the current study, this begs the question of, were the participants more efficient movers or was there a difference in the methods used to collect, analyze and interpret the FMS scores. It could be argued that the eligibility criteria used in the current study versus the previous studies might account for this difference. Specifically, the current study required that participants were injury free

so those currently injured or in pain were not eligible to participate. This resulted in no scores of 0 being recorded or used in the data analysis. Previous studies could have a lower FMS total score due to scores of 0 being included. Therefore, we do not propose that our cohort were more efficient movers, but rather, the differences seen in mean FMS total scores were likely due to the methodology (i.e., zeros not included in the calculations of TS), resulting in higher scores.

As hypothesized and consistent with other studies, FMS TS increased across hockey age groups and stage of maturity. These data are consistent with similar studies (Boguszewski et al. 2017; Marques et al. 2017; Portas et al. 2016; Lloyd et al. 2014) comparing FMS scores and chronological age in adolescent athletes. When our athletes were categorized by hockey age or stage of maturity, FMS total scores revealed a linear increase across all groups. This provides reassurance that our FMS TS is consistent with similar studies and allows for the further breakdown of the individual movement patterns. Unique to our research, we determined that physical maturity did not contribute to FMS TS beyond chronological age. This is because of the significantly strong correlation between age (years) and maturity (\pm years away from PHV) and this relationship resulted in no significant differences.

Unlike previous studies that interpreted scores based primarily on FMS TS, the current study also included a more in-depth analysis of the seven movement scores. This included; (i) analyzing subgroups of movement screens; FMS_{move}, FMS_{flex}, FMS_{stab}, (ii) analyzing frequencies of individual movement scores (1, 2, 3's), and (iii) frequency of left/right asymmetries. It was anticipated that the proposed analyses would provide a better interpretation of FMS scores obtained in adolescents.

FMS_{move} consisted of the DS, HS and ILL. When analyzed across the four hockey age groups, results revealed that Midget players scored significantly higher than Pee wee players. However, when analyzed by the five stages of maturity, there were no significant differences in FMS_{move}. This could suggest that when grouped by hockey age, Pee wee players (11-12 years old) may have exhibited less control or coordination due to what has been termed ‘adolescent awkwardness’, used often to reflect a temporary disruption in motor control performance associated with this age, at this given stage of development (Philippaerts et al., 2006). Lloyd et al. (2015) proposed the under 13’s in their study might have been temporarily restricted and performance might have been limited as the players adjust to executing motor skills with long limbs. This could provide some insight into interpreting FMS scores by physical development as opposed to FMS TS. That said, this could also be simply a result of the participants being re-grouped from four hockey age groups to the five stages of maturity, therefore the increase becomes masked. It might be suggested that, the difference across groups could be statistical.

FMS_{flex} consisted of SM and ASLR. There was no significant difference in FMS_{flex} scores across the four hockey age groups or the five stages of maturation. These results are similar to previous studies suggesting that flexibility does not significantly change through adolescence (Feldman et al., 1999). Similarly, there was no significant difference in sit and reach measurements across the four hockey groups, with the exception of Midget and maturity stage 5. The increase in flexibility at the Midget level may be a function of dedicated training as opposed to growth and development.

FMS_{stab} consisted of TSPU and RS. Previous literature has reported that the increase in FMS TS scores among post-PHV participants can be primarily explained by

the increase in FMS_{stab}. In the current study, Midget players scored significantly higher than all three age groups and both maturity stage 4 and 5 players scored significantly higher than maturity stage 1 and 2 players on the FMS_{stab}. These findings are consistent with previous literature (Boguszewski et al., 2017; Lloyd et al 2015; Portas et al. 2016; Marques et al. 2017), suggesting that the player's ability to achieve a high FMS TS is primarily due to their TSPU and RS scores. That said, a closer look at the individual scores revealed that 94% of the participants scored a 2 on RS consistently across all ages and stages, however TSPU scores were more variable. The differences in FMS_{stab} across age and maturity stage were due to differences in the TSPU scores. The TSPU requires a significant amount of upper body strength to complete the screen without compensation. For males, the participant is required to raise the torso in one piece and finish the movement at full arm extension, which is a difficult movement and requires significant upper body strength to perform properly. Furthermore, strength changes post-PHV may explain why Midget (Stage 5) players scored significantly higher than all other groups and why Bantam (Stage 4) players scored significantly higher than Atom (Stage 1) players. Thus, the TSPU is likely more a measure of upper body strength than stability in adolescents. Boguszewski et al (2017), also reported that their male participants, practicing hockey or not, scored higher post-PHV on TSPU than pre-PHV participants. To further interpret our findings, we used grip strength as a comparator measure of strength. Grip strength measures significantly increased across both hockey age groups and stages of maturity. Furthermore, there was a moderate, yet significant positive correlation between grip strength and FMS_{stab}, suggesting that FMS_{stab} scores may also represent strength gains in adolescents.

An analysis of frequency of individual scores 1, 2, and 3's allowed for the identification of movement patterns that elicited compensations. Mokha and colleagues (2016) combined the scoring of a 0 or 1 and/or had an asymmetry and found that those participants were 2.73 times more at risk for an injury, as identified using injury tracking. In the current study, 71% of participants recorded a score of 1 on an individual movement screen. These findings are consistent with the previous research associated with adolescent populations (Marques et al. 2017; Lloyd et al. 2016; Parenteau-G et al. 2014) and potentially suggest that, scoring a 0 or 1 on the FMS is not uncommon in an athletic adolescent population and coaches/trainers should be made aware of those compensations prior to participation in activity.

When investigating variation of scores within a movement screen, it was determined that TSPU had the greatest variation across the hockey age groups: 15 Atom participants (52%) scored a 1, compared to 8 Peewee (32%) , 9 Bantam(29%), and only 1 Midget (4%) player. As stated above, given that TSPU requires significant upper body strength, scoring a 1 on this movement screen in adolescents may not reveal a risk for injury, but rather might reveal their lack of upper body strength to perform this specific screen. Parenteau-G et al. (2014) found 45% of participants scored a 0/1 on TSPU and also found 42% participants scored 0/1 on ASLR. These findings lead us to believe that it is more common for adolescents to score a 0 or 1 as a function of strength as opposed to those scores indicating a risk for injury.

The current study analyzed the frequency of asymmetries by counting the number of movement screen scores that revealed left/right differences. Although the frequencies of asymmetries lead to no significant findings across both hockey age groups and stages

of maturity it is still important to recognize the number of participants that identified with an asymmetry. Results revealed 44% of participants had an asymmetry. A comparison of frequency of asymmetries was conducted across the four hockey age groups and the five maturation stages. Bantam players revealed the greatest frequency of asymmetries (24%). Bantam players also were the highest to score left/right differences on one particular screen, the ILL, at 35.5%. Furthermore, the highest number of asymmetries was revealed on the HS for all participants while RS had the lowest number of asymmetries. It is difficult to provide a rationale for why Bantam players had the greatest frequency of asymmetries, as no other FMS research has published on asymmetries by age group.

However, when comparing asymmetries across hockey age groups versus stages of maturity, maturity stage 1 (29.5%) and maturity stage 2 (17%) revealed asymmetries on the HS screen. However, Atom (26.7%) and Pee wee (28%) participants identify with an asymmetry on the HS screen. This suggests that the less mature Pee wees revealed an asymmetry on the HS. The HS examines stride mechanics and the ability to maintain left/right balance on one leg. It is possible that the least mature athletes (maturation stage 1/Atom) have not developed the ability to balance on both sides of the body, leading to the increase in asymmetries for that stage of maturation. Essentially, there are several unknowns related to how specific asymmetries are influenced by age and stages of maturity, but the current study provides some preliminary insight into how age and stages of maturity can impact certain movement patterns.

The secondary purpose of the study was to determine if a relationship exists between asymmetries identified by the FMS and years of participation in unilateral sport-specific training, such as for ice hockey. Consistent with Boguszewski et al. (2017), age

significantly correlated with total years of hockey participation, meaning older athletes had invested more years in hockey-specific training. However, significant correlations between frequencies of asymmetries and years of playing hockey or years of playing at the AAA level of hockey were not found. This result was surprising, as it was anticipated that hockey could be identified as a unilateral sport. It was also anticipated that the greater number of years of experience would be associated with a higher likelihood of developing left/right dominance creating movement asymmetries. However, that was not the case. These findings could be related to the fact that the unilateral aspect of ice-hockey is typically upper body movements where a player is either right or left handed. However, of the seven individual FMS screens, only shoulder mobility assesses upper body asymmetries. That said, because of how the FMS individual movements are designed, scoring an asymmetry on the left side of the body does not always mean an individual has a left side movement inefficiency, rather the individual has an asymmetry and needs further diagnosis from a medical professional. Therefore, if ice-hockey does create asymmetries, the FMS screen may not identify them.

5.1 Practical Application

Results of the current study provided insight into the application and interpretation of FMS scores in an athletic adolescent population. Results suggested that older and more physically mature adolescents typically score higher on the FMS. However, physical maturity does not predict FMS TS beyond what may be predicted by chronological age. Furthermore, the use of the FMS cut-off score of less than or equal to 14 points may not be appropriate to determine injury risk due to the lack of interpretation and somewhat inconsistent results throughout research in an adolescent population.

Lower scores in this cohort may be more representative of the lack of strength rather than inefficient movement patterns as a function of age and maturity.

In an adolescent population, sit and reach scores had the strongest relationship to FMS TS compared to all other independent variables (age, maturity and relative strength). With flexibility being a major contributor to the successful completion of four out of the seven individual movement screens associated with the FMS, it could be suggested that flexibility should be the focus of fitness programs in an adolescent population to insure proper functional movement patterns.

Furthermore, it appeared that the unilateral nature of ice hockey did not create any association between asymmetries and years of participation as assessed during the limited exposure analyzed for the purpose of the study. Study outcomes provide coaches and trainers with insight into understanding movement development and further awareness that inefficient movement patterns may be a reflection of normal growth and development in an adolescent population.

5.2 Limitations

Limitations of the study include that participants were only males, limiting generalizability. However, the decision to include only males was related to understanding the fact that rates of development for males and females are different, as well as the lack of AAA hockey leagues for females. Therefore, including females would have made the data less homogeneous and interpretation would have been a challenge.

A second limitation was that the sports cohort was limited to ice-hockey players only, which limits generalizability to other sports and non-athletes. Given that other studies have reported on different sport populations, the targeted focus of ice hockey was

warranted and builds on the existing literature. Thirdly, maturation was assessed using predicted age of peak height velocity based on the age of peak height velocity (APHV) equation, as described by Mirward and colleagues (2002). However, from a practical perspective, the predictive equation is a reliable, non-invasive, time-efficient measuring tool to assess maturity in youth populations.

Finally, the data collected were cross-sectional, limiting the ability to see differences in participants as they develop across stages of maturity and chronologically.

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TABLES

Table 1

Skeletal Maturity in Hockey Players

Sport (Hockey) (level)	Method	N (# of participants)	Chronological Age (y)	Skeletal Age (y)	Late Maturing	On Time	Early Maturing	Mature
Peewee	GP	205	12+		76 (37%)	100 (49%)	29 9 (14%)	
Bantam	TW2 RUS	68	13.9±0.5	15.6±0.8	0 (0%)	12 (18%)	56 (82%)	
Midget	TW2 RUS	85	15.7±0.6		0 (0%)	31 (36%)	32 (38%)	22 (26%)
Junior	TW2 RUS	57	17.7±0.7		0 (0%)	12 (21%)	0 (0%)	45 (79%)

(Bouchard, Roy, LaRue 1969) & (Lariviere 1986) Found in (Malina, 2011 p .935)

Note. Legend for Methods; GP= Greulich and Pyle; TW2 RUS= Tanner and Whitehouse 2 Radius, Ulna, Short Bone.

Table 2

Maturity Categories

Category	Definition
1	negative maturity offset greater than -2 (-2 APHV)
2	negative maturity offset greater than -1 (-1 APHV) and less than -2
3	± 1 year of PHV
4	any positive maturity offset greater than $+1$ ($+1$ APHV) and less than $+2$
5	any positive maturity offset greater than $+2$ ($+2$ APHV)

Note. Outcomes of age (years away) from peak height velocity equation. Age of peak height velocity (APHV) was used to categorize participants into one of the five stages of maturation.

Table 3

Descriptive Statistics for Study Participants

DESCRIPTIVES	ATOM	PEEWEE	BANTAM	MIDGET
Birth year	2008/2009	2006/2007	2004/2005	2003/2002
Age (years) M (SD)	9.8 (.52)	11.8 (.56)	13.9 (.54)	15.7 (.61)
Distribution (n)	29	25	31	26
>-2 yrs. Away from	29	11		
APHV (n)		14	3	
Between -2 and -1			26	3
yrs. (n)			2	12
Between -1 and +1				11
yrs. (n)				
Between +1 and +2				
yrs. (n)				
>+2 yrs. Away from				
PHV (n)				
Weight (kg) M (SD)	33.8 (5.2) *	46.4 (7.7) *	56.6 (9.2) *	71.0 (7.2) *
Height (cm) M (SD)	139.4 (5.2) *	154.4 (7.6) *	167.4 (9.4) *	177.0 (5.6) *
Sitting height (cm)	70.0 (3.5) *	75.8 (3.2) *	84.7 (4.6) *	89.8 (4.3) *
M (SD)				
Maturity Offset	-3.5 (0.5) *	-1.9 (0.5) *	.04 (0.8) *	1.8 (0.7) *
(years) M (SD)				

*Significant increases across all groups

An alpha level of $p \leq .05$ was used for all analyses

Table 4

Descriptive Statistics of Level of Sports Participation by Hockey Age Group

HOCKEY AGE GROUP	YEARS OF AAA EXPERIENCE	OTHER COMPETITIVE SPORT PLAYED	OTHER COMPETITIVE SPORT LEVEL
Atom (n=29)	1 = 37.9%	N/A = 5	N/A = 5
	2 = 48.3%	Soccer = 11	House League = 4
	3 = 13.8%	Baseball = 6	Travel = 13
		Lacrosse = 5	Elite = 7
		Golf = 2	
Peewee (n=25)	1 = 16.0%	N/A = 2	N/A = 2
	2 = 12.0%	Soccer = 11	House League = 4
	3 = 12.0%	Baseball = 6	Travel = 13
	4 = 52.0%	Lacrosse = 6	Elite = 6
	5 = 8%		
Bantam (n=31)	1 = 16.1%	N/A = 12	N/A = 12
	2 = 6.5%	Soccer = 9	House League = 5
	3 = 9.7%	Baseball = 3	Travel = 8
	4 = 6.5%	Lacrosse = 7	Elite = 6
	5 = 9.7%		
	6 = 25.8 %		
	7 = 25.8%		
Midget (n=26)	1 = 3.8%	N/A = 9	N/A = 9
	2 = 15.4%	Soccer = 6	House League = 1
	4 = 15.4%	Baseball = 4	Travel = 9

5 = 7.7%

Lacrosse = 5

Elite = 7

6 = 7.7%

Volleyball = 1

7 = 11.5%

Rugby = 1

8 = 23.1%

9 = 15.4%

Table 5

Functional Movement Screen Total Scores across Hockey Age-Groups

FUNCTIONAL MOVEMENT SCREEN	ATOM M (SD) RANGE	PEEWEE M (SD) RANGE	BANTAM M (SD) RANGE	MIDGET M (SD) RANGE
FMS _{TOTAL}	14.6 (2.3) *	15.1 (1.5) *	15.8 (1.6)	16.7 (1.6) *
	11-19	12-18	13-19	14-21
FMS _{MOVE}	6.5 (1.4)	6.2 (1.0) *	6.5 (1.0)	7.2 (0.9) *
	3-9	4-8	4-8	5-9
FMS _{FLEX}	4.7 (0.9)	5.0 (0.8)	5.1 (0.8)	4.8 (0.9)
	3-6	3-6	3-6	3-6
FMS _{STAB}	3.4 (0.8) **	3.9 (0.7) *	4.1 (0.9) ***	4.7 (0.6) *
	2-5	3-5	3-6	3-6

Legend:

The individual movement screens were grouped into three sub groups: FMS_{move} (3 movement tests; DS, HS, ILL); FMS_{flex} (2 mobility tests; SM and ASLR), 2 FMS_{stab} (2 stability tests; TSPU and RS) (Portas et al., 2016)

* Significantly different than both * and **

*** Significantly less than only **

Difference between groups: * $p < .05$

Table 6

Functional Movement Screen Total Scores across Stages of Maturation

FUNCTIONAL MOVEMENT SCREEN	MATURITY STAGE 1 M (SD) RANGE	MATURITY STAGE 2 M (SD) RANGE	MATURITY STAGE 3 M (SD) RANGE	MATURITY STAGE 4 M (SD) RANGE	MATURITY STAGE 5 M (SD) RANGE
FMS _{TOTAL}	15.0 (2.2)** 11-19	14.8 (1.5)* 13-19	15.8 (1.56) 13-19	16.6 (1.5)** 14-18	17.0 (1.8)* 14-21
FMS _{MOVE}	6.4 (1.3) 3-9	6.4 (0.9) 5-8	6.6 (0.9) 5-8	7.0 (1.8) 4-8	7.3 (1.1) 5-9
FMS _{FLEX}	4.9 (0.9) 3-6	4.7 (0.8) 3-6	5.1 (0.8) 3-6	4.9 (1.0) 3-6	5.0 (0.8) 4-6
FMS _{STAB}	3.6 (0.9)** 2-6	3.8 (0.7)* 3-5	4.0 (0.7) 3-5	4.8 (0.4)** 4-5	4.7 (0.8)* 3-6

Legend:

The individual movement screens were grouped into three sub groups: FMS_{move} (3 movement tests; DS, HS, ILL); FMS_{flex} (2 mobility tests; SM and ASLR), 2 FMS_{stab} (2 stability tests; TSPU and RS) (Portas et al., 2016)

* Significantly different than both * and **

** Significantly different than only ** (Stage 4 is significantly higher in both total and stab than stage 1)

Difference between groups: *p < .05

Table 7

Frequencies of 1, 2, 3's of Individual FMS Screen Scores across Hockey Age Group

Hockey Age Group	Atom			Peewee			Bantam			Midget		
	1	2	3	1	2	3	1	2	3	1	2	3
	n	n	n	n	n	n	n	n	n	n	n	n
Deep Squat	4	15	10	6	16	3	4	18	9	1	16	9
Hurdle Step	2	25	2	1	21	3	0	27	4	0	21	5
In-Line Lunge	6	9	14	1	15	9	1	21	9	0	7	19
Shoulder Mobility	4	10	15	0	7	18	1	15	14	2	10	14
Active Straight Leg Raise	1	17	11	3	13	9	2	15	14	2	13	1
Trunk Stability Push-up	15	13	1	8	12	5	9	9	13	1	7	18
Rotary Stability	4	25	0	0	25	0	1	29	1	0	25	1

Table 8

Frequencies of 1, 2, 3's of Individual FMS Screen Scores across Stages of Maturation

Maturation Stage	Stage 1			Stage 2			Stage 3			Stage 4			Stage 5		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Deep Squat	1	21	12	3	11	3	2	19	7	1	7	6	1	7	3
Hurdle Step	2	36	3	1	14	2	0	24	4	0	12	2	0	8	3
In-Line Lunge	7	14	20	0	12	5	0	19	9	1	5	8	0	2	9
Shoulder Mobility	4	11	26	0	7	10	1	7	20	2	5	7	1	3	7
Active Straight Leg Raise	2	22	17	3	10	4	1	15	12	2	5	7	0	6	5
Trunk Stability Push-up	18	18	5	6	7	4	8	11	9	0	3	11	1	2	8
Rotary Stability	4	36	1	1	16	0	0	28	0	0	14	0	0	10	1

Table 9

Frequencies of Asymmetries across Hockey Age Groups

Hockey Age Group	Atom n (%)	Peewee n (%)	Bantam n (%)	Midget n (%)
Hurdle Step	8 (26.7%)	7 (28%)	5 (16.1%)	8 (30.7%)
In-Line Lunge	6 (20.7%)	5 (20%)	11 (35.5)	4 (15.4%)
Shoulder Mobility	6 (20.7%)	5 (20%)	5 (16.1%)	3 (11.5%)
Active Straight Leg Raise	0 (0%)	3 (12%)	2 (6.5%)	4 (15.4)
Rotary Stability	1 (3.4%)	1 (4%)	1 (3.2%)	0 (0%)

*No significant differences were found across groups

Difference between groups: $p < .05$

Table 10

Frequencies of Asymmetries across the Stages of Maturation

Maturation Stage	Stage 1 n (%)	Stage 2 n (%)	Stage 3 n (%)	Stage 4 n (%)	Stage 5 n (%)
Hurdle Step	12 (29.5%)	3 (17.6%)	7 (25%)	3 (21.4%)	8 (25.2%)
In-Line Lunge	7 (17.1%)	6 (35.3%)	8 (28.6%)	4 (28.6%)	1 (9.1%)
Shoulder Mobility	7 (17.1%)	4 (23.4%)	5 (17.9)	1 (7.1%)	2 (18.2%)
Active Straight Leg Raise	0 (0%)	3 (17.6%)	2 (7.1%)	3 (21.4%)	1 (9.1%)
Rotary Stability	2 (4.9%)	1 (5.9%)	0 (0%)	0 (0%)	0 (0%)

*No significant differences were found across groups

Difference between groups: $p < .05$

FIGURES

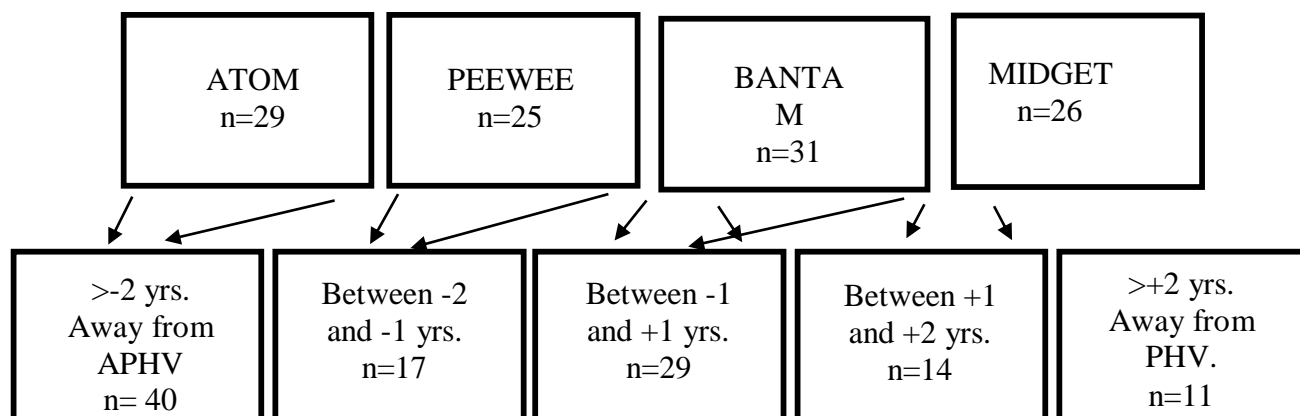


Figure 1. Participant distribution after determining age (years away) from peak height velocity.

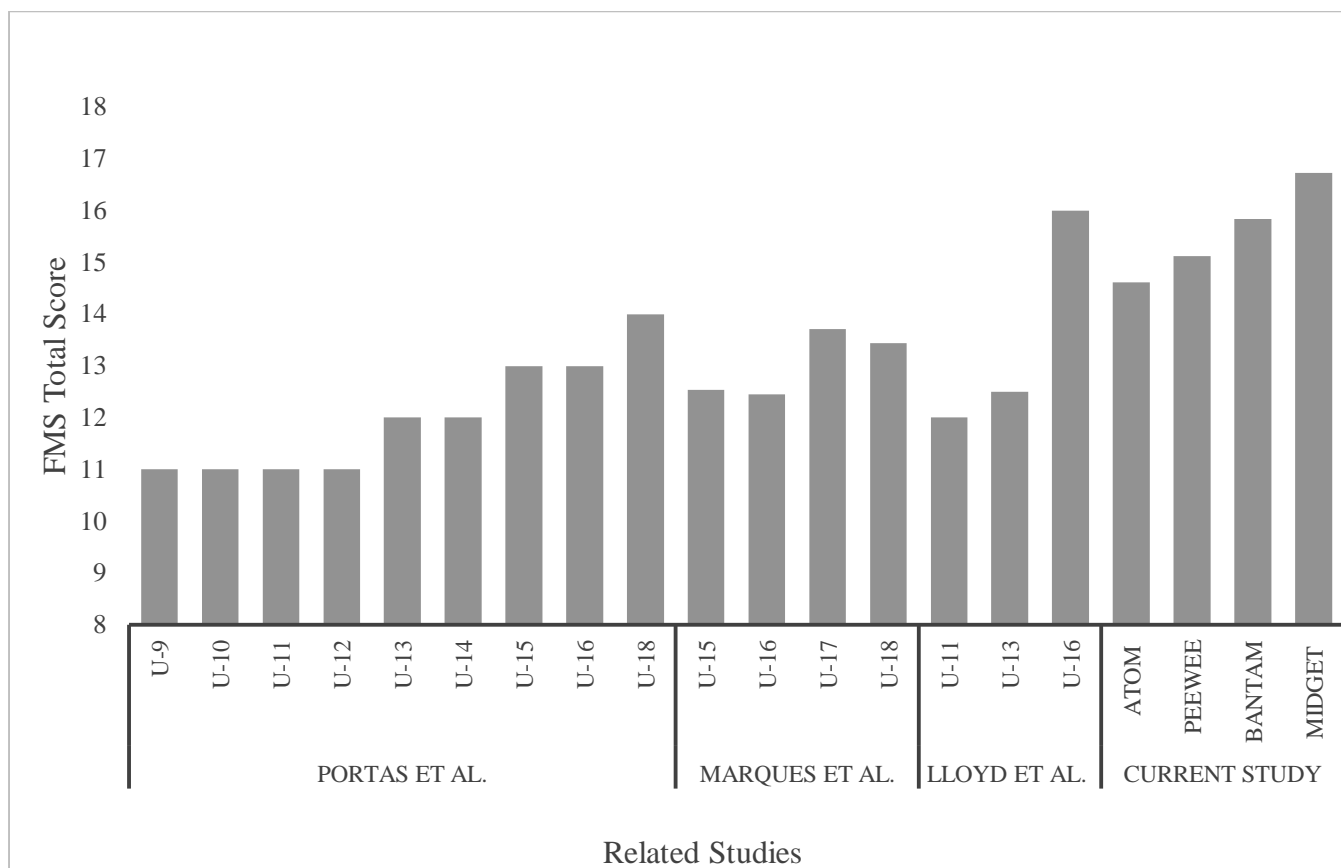


Figure 2. Similar Studies in youth athletes comparing Total FMS Scores.

Note: In ice hockey, each category spans two years of chronological age: atom (9-10 years), peewee (11-12 years) bantam (13-14 years) midget (15-16 years).

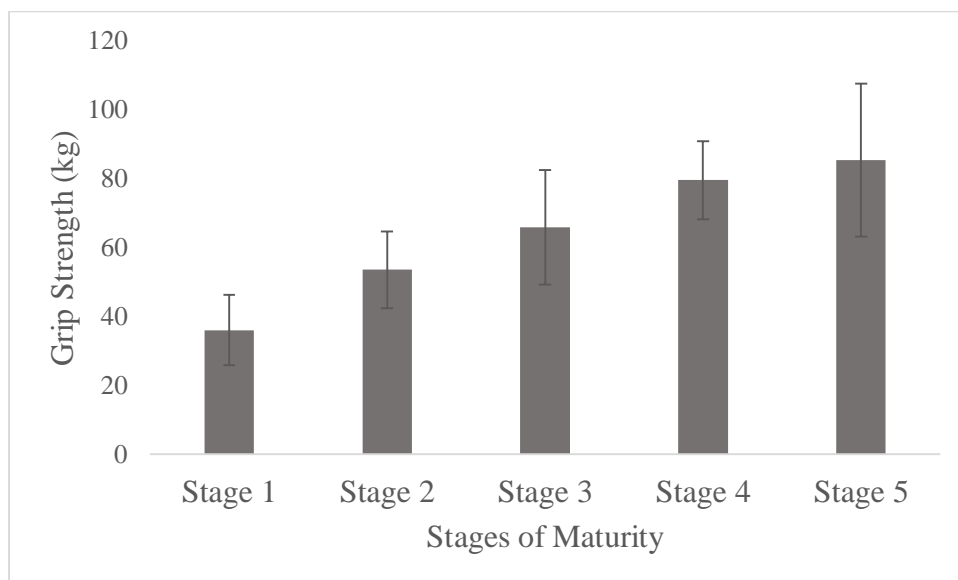


Figure 3. Grip strength across five stages of maturity

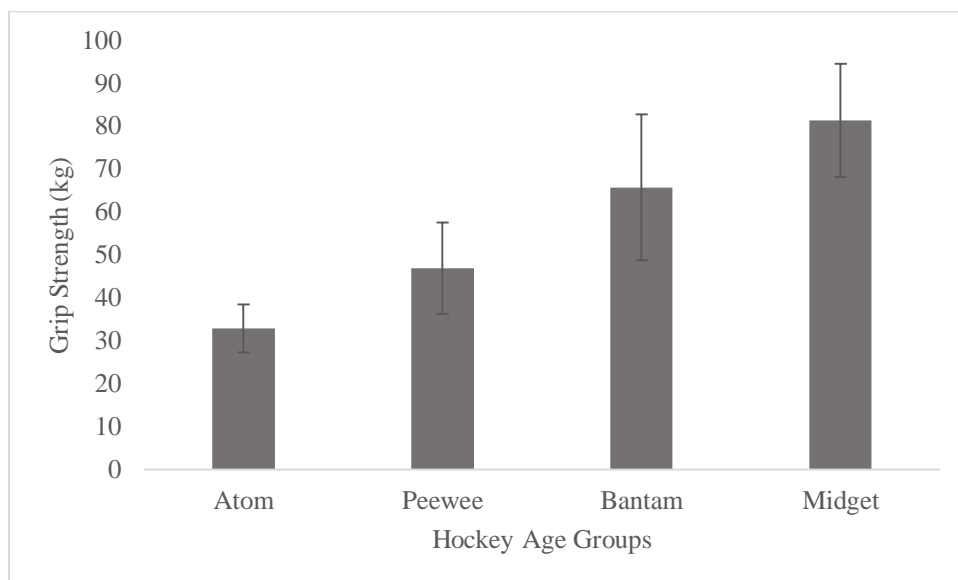


Figure 4. Grip strength across four hockey age groups

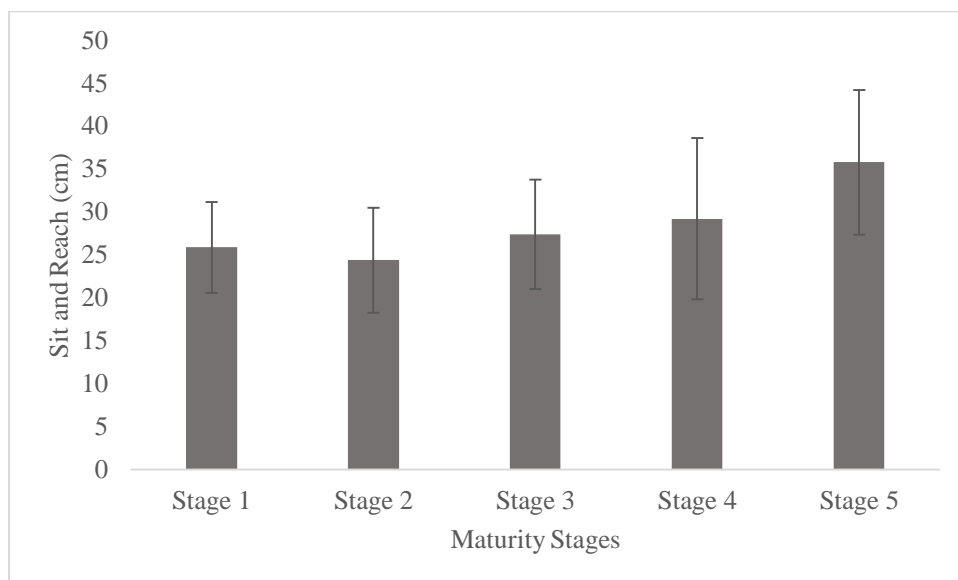


Figure 5. Sit and reach scores across five stages of maturity

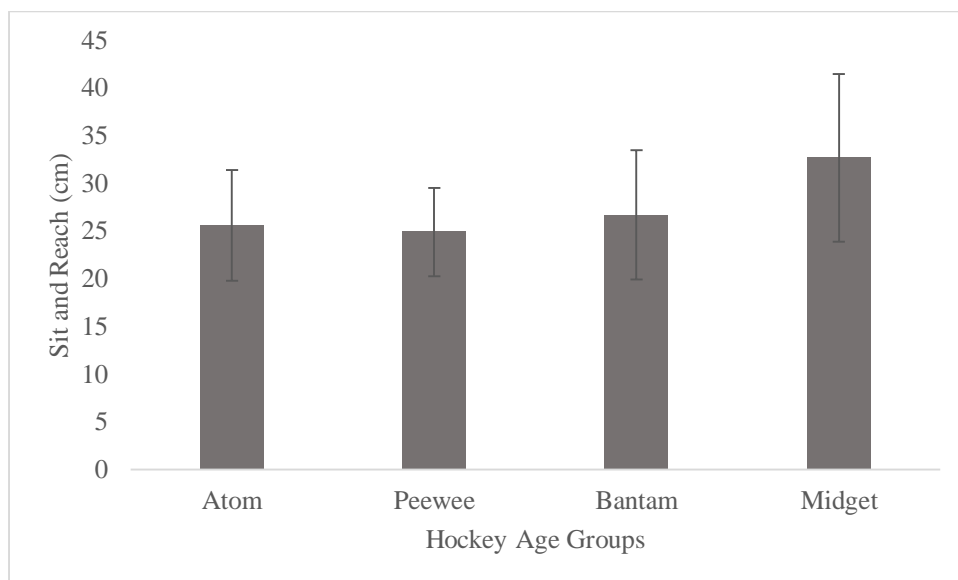


Figure 6. Sit and reach scores across four hockey age group

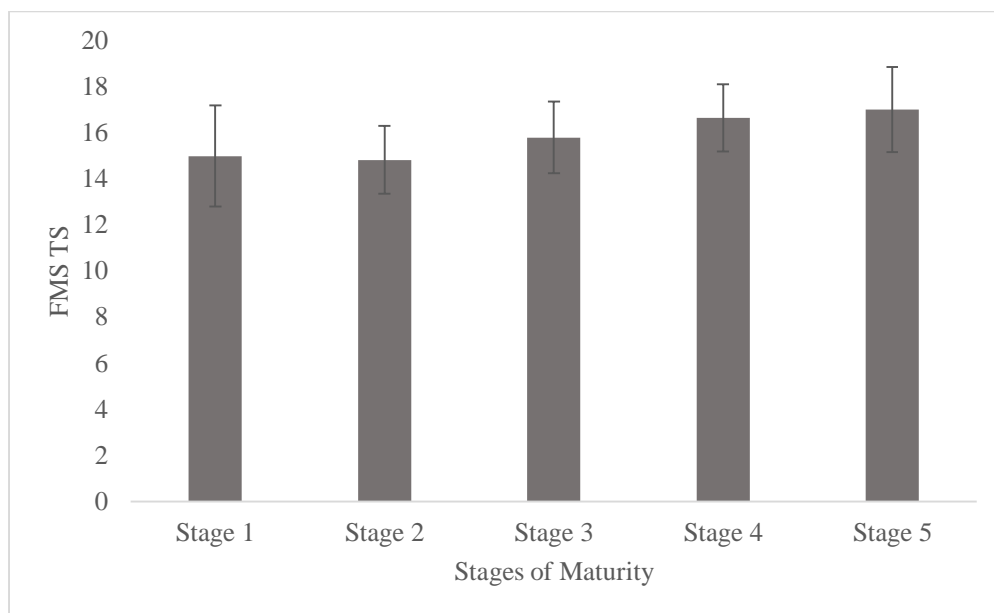


Figure 7. FMS Total Scores across five stages of maturity

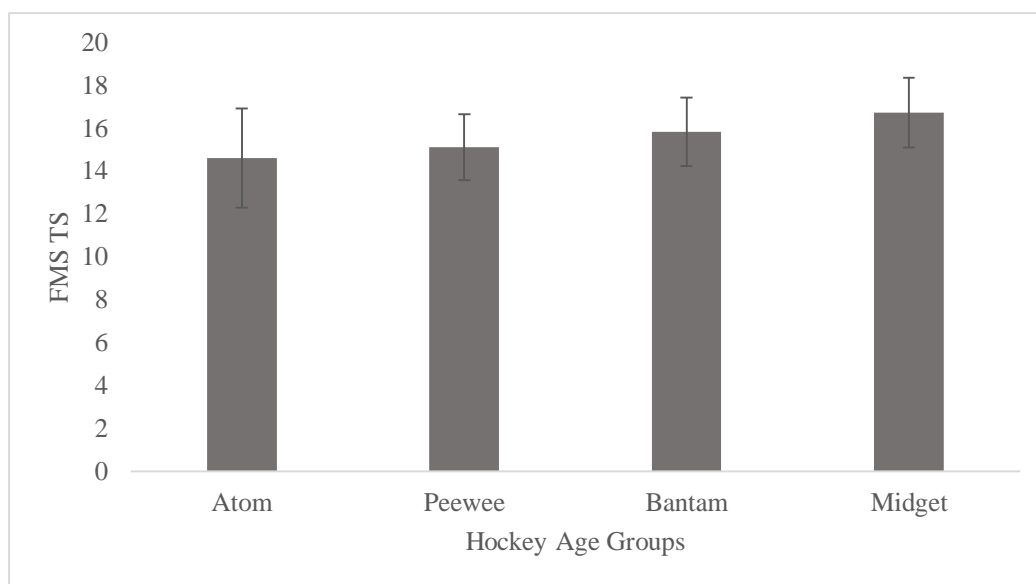


Figure 8. FMS Total Scores across four hockey age group

APPENDIX A - LETTER OF INVITATION

A Cross-Sectional Analysis Of Functional Movement Screen (FMS) Scores in Male AAA Minor Hockey Players

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INVITATION

You are invited to participate in a Master's thesis research project. The purpose of the research is to compare and contrast Functional Movement Screen (FMS) data across five stages of maturation in male adolescent ice-hockey players. FMS is a tool used to assess risks associated with movement inefficiencies and is primarily used in pre-participation screening of an athletic population.

Please note participants wishing to participate in the research must be injury free. Injury free refers to any individual who has not sustained an injury that has taken them out of physical activity in the last three months.

WHAT'S INVOLVED

Included in this package is this letter of introduction detailing the study, consent/assent forms, and a hockey experience questionnaire.

Should you wish to participate in the study, you are asked to complete the forms in the privacy of your own home and email forms back to the principal student researcher. Upon receipt of the completed forms, the principal student researcher will contact you to schedule and confirm the assessment date/time.

The study will be conducted during the 2018-19 hockey season and take place at the Seymour Hannah Sports and Entertainment Centre. Assessments will take one hour of your time.

Assessments will include: anthropometric measures (height, sitting height, weight), a measure of strength (grip strength), a measure of flexibility (sit & reach test) and the Functional Movement Screen (FMS)(Appendix D). The following provides a detailed description of the assessment methods.

We acknowledge that confidentiality cannot be guaranteed because other participants will be completing the testing at the same time, however, not at the same station. The testing will be done in a private dressing room at the arena. If you wish to be involved in the study, but do not want to be tested with others, a separate appointment can be arranged with the student principal investigator and another research assistant at a time that works for you.

1. Sport Experience Questionnaire

This brief sport experience questionnaire should be completed prior to the assessment and was developed for the study to profile the competitive experience activities engaged in. The questionnaire should take only 5 minutes and is included in this package. Please complete and bring this document to your assessment.

Assessment Battery:

2. Anthropometric Measures

Anthropometric measurements including: height (cm), sitting height (cm), and weight (kg).

3. Grip Strength

To measure your grip strength, you will be asked to stand in an upright position with your shoulder and elbow tucked into the side of the body while flexed slightly. The handheld dynamometer will be placed in your hand and you will be encouraged to squeeze it as hard as possible for 5 seconds. You will alternate hands for a total of 3 times with a 15 second break in between each hand. Your highest score will be recorded.

4. Flexibility Assessment

You will be seated on the floor with both legs fully extended, shoulder-width apart, and feet placed flat against a box. With one hand on top of the other and the knees fully extended, slowly reached forward (without jerking) as far as possible, sliding the hands across the top of the ruler, and hold the final position at least two seconds. The score, in centimeters, will be recorded as the final position of the fingertips on or towards the ruler. Higher scores indicate better performance. The score is negative if the participant could not touch the front of the box with his fingertips, where the “0” score is. The test will be performed twice, and the highest score will be recorded.

5. Functional Movement Screen

You will be briefed on the purpose of conducting Fundamental Movement Screen. FMS consists of a battery of seven movements, including: deep squat (DS), hurdle step (HS), in-line lunge (ILL), shoulder mobility (SM), active straight leg raise (ASLR), trunk stability push-up (TSPU), and rotary stability (RS). All movements will be scored from 0-3 and you will be given three attempts to complete the movement to the best of your ability, with the highest score recorded. For the bilateral movements (HS, ILL, SM, ASLR and RS), both sides are scored independently. Three post-screening clearing tests will also be conducted to identify if pain is present during the movements.

POTENTIAL BENEFITS AND RISKS

Potential benefits of participation include the opportunity to complete the functional movement screen and receive your total score on the Functional Movement Screen. As part of this assessment, you may feel slight pain or discomfort as you perform the movement. Although unlikely, if you experience pain or discomfort you should immediately stop the movement and inform the assessor. The FMS does not elicit pain, but rather detects it and, once detected, the movement is stopped immediately.

This study also has the potential to benefit the scientific and athletic community by contributing to our knowledge of implementing and interpreting the FMS in youth populations.

Potential risks are minimal. Even though other participants may be in the room with you, you will be individually tested, and other participants will not be made aware of your scores.

CONFIDENTIALITY

FMS assessment is conducted in a circuit-type station fashion in a private dressing room with other participants, however, all information you provide is considered personal data. To avoid exposure of personal data and ensure confidentiality, the researchers will input all scores onto the data sheet. Other participants will not be aware of how you scored on the FMS. The anthropometric measures and strength assessment/ flexibility assessments will be completed individually to maintain confidentiality. You will be assigned ID codes by the researcher so that personal identifiers will not appear on the data forms.

Furthermore, coaches are not a part of the research project and will not have access to the collected data.

Following study completion, electronic copies of the data will be retained for a period of five years. The data will be stored on a research dedicated portable hard drive that is password protected by the principal student researcher. Access to these data will be restricted to the student principal investigator and faculty supervisor.

VOLUNTARY PARTICIPATION

Participation in this study is voluntary and not mandatory. Participation, or not, will not affect your standing with your current or future team. Should you wish to withdraw from this study, you may do so by verbally informing the student principal investigator or faculty supervisor without any penalty. If you choose to withdraw, your data will be destroyed by deleting any files and shredding any information related to your participation. Your data will not be shared or used for further analysis.

PUBLICATION OF RESULTS

A summary of the results will be available and provided upon your request upon completion of the study. This will include all anthropometric data along with a personalized summary with both total FMS scores and number of left/right asymmetries and a comparison to average group scores. Furthermore, results of this study may be published in academic or practitioner's journals and/or presented at scientific conferences to advance our knowledge of the relationship between functional movement screen scores and maturity status in youth populations. Only group data (i.e. no identifiable results) will be reported to an academic or practitioner's journal.

ETHICS CLEARANCE

If you have any questions about this study or require further information, please contact Dr. Kelly Lockwood or Steve Dol using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University **(17-130- LOCKWOOD)**. If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.

CONTACT INFORMATION

If you are interested in participating, please contact the principal student investigator Steve Dol at sd09lw@brocku.ca or 519-209-4220 to set up an appointment to be tested.

You will be asked to complete an Informed Consent and bring the emailed copy with you. Please keep a copy of this form for your records. Thank you for your assistance in this project.

APPENDIX B - CONSENT FORM

I agree to participate in the study described above. I have made this decision based on the information I have read in the Information-Consent Letter and assent that:

- I have had the opportunity to ask questions and receive any additional details I wanted about the study and
- I understand that I may ask questions anytime during the study.
- I understand that I may withdraw this consent at any time.
- I understand that this is not a team required activity and I am not obligated as a player to participate in the study.
- I understand that the assessments will take place in groups with other participants viewing my performance, however, only the researchers will see my scores.

For Participants and Guardians to complete:

Participant Assent:

In signing this form, I _____
(Participant's Name) and _____ (Guardian's Name)
acknowledge that I have received an explanation about the nature of the study and its purpose and I give my permission to participate in the research as described above conducted by Steve Dol and Dr. Kelly Lockwood.

Parental/Guardian Consent:

I _____ (Guardian's Name) give my permission
for _____ (Participant's Name) to participate in the research
as described above conducted by Steve Dol and Dr. Kelly Lockwood. I have made this
decision based on the information I have read in the Information-Consent Letter.

Participant's Name: _____

Participant's Signature: _____

Guardian's Name: _____

Guardian's Signature (if under 18): _____

Date: _____

APPENDIX C – HOCKEY EXPERIENCE QUESTIONNAIRE

FOR RESEARCHER USE ONLY

Participant ID: _____

Date of Birth (M/D/Y): _____ / _____ / _____ Weight (kg): _____

Height (cm): _____ Sitting Height (cm): _____

Sport Dominance (L/R): _____ Handedness (L/R): _____

Grip Strength (kg): R: _____ L: _____ Reach and Sit (cm): _____

(Current Hockey Team: City, Name and Level (Example: Niagara North Stars AAA
Peewee)

How many hours of scheduled hockey do you participate in during a given week? (Please circle)

2 or less

3-4 hours

5+ hours

How many seasons have you played hockey at the AAA level?

How many seasons have you played hockey? _____

Do you play another competitive sport? _____

If so, what team/level? (Ex. AAA Lacrosse, AA Soccer, Competitive Tennis etc.)

Have you missed time (practice or a game) because of injury in the last 3 months?

If so, what was the injury and how long did you miss activity?

APPENDIX D - FUNCTIONAL MOVEMENT SCREEN

(Adapted from Cook, Burton, & Hoogenboom, 2006)

(Photos retrieved from www.functionalmovement.com)

Deep Squat



Hurdle Step



In-Line Lunge



Assess bilateral, symmetrical and functional mobility of the hips, knees, and ankles	Assess the bilateral functional mobility and stability of the hips, knees, and ankles	Assess torso, shoulder, hip and ankle mobility and stability, quadriceps flexibility, and knee stability
--	---	--

Shoulder Mobility



Assess bilateral shoulder range of motion, combining internal rotation with adduction and external rotation with abduction

Active Straight Leg Raise



Assess active hamstring and gastroc-soleus flexibility while maintaining a stable pelvis and active extension of opposite leg

Trunk Stability Push-up



Assess trunk stability in the sagittal plane while a symmetrical upper-extremity motion is performed

Rotary Stability



Assess multi-plane trunk stability during a combined upper and lower extremity motion

APPENDIX E - FUNCTIONAL MOVEMENT SCREEN DATA SHEET

Participant ID: _____ Rater's Name: _____

Functional Movement	Score	Dysfunction(s)
1. Deep Squat	0 1 2 3	
2. Hurdle Step Shank (cm) _____	Overall 0 1 2 3 _____	
	Left Leg 0 1 2 3 Right Leg 0 1 2 3	
3. In-Line Lunge	Overall 0 1 2 3 _____	
	Left Leg 0 1 2 3 Right Leg 0 1 2 3	
4. Shoulder Mobility Hand Length _____	Overall 0 1 2 3 _____	
Shoulder Impingement: Y / N	Left Shoulder 0 1 2 3	
Left / Right / Both	Right Shoulder 0 1 2 3	
5. Active Straight Leg Raise	Overall 0 1 2 3 _____	
	Left Leg 0 1 2 3 Right Leg 0 1 2 3	
6. Push Up Back extension pain: Y / N	0 1 2 3	
7. Rotary Stability	Overall 0 1 2 3	
	0 1 2 3	
Low back pain: Y / N	0 1 2 3	
Total Score	_____ / 21	

Score	Standardized Criteria (Cook, Burton & Hoogenboom, 2006)
3	perfect repetition
2	completion of a repetition with compensation
1	an inability to complete the movement
0	pain was elicited during the movement

APPENDIX F - FEEDBACK LETTER

A Cross-Sectional Analysis of Functional Movement Screen (FMS) Scores in Male AAA

Minor Hockey Players

Kelly Lockwood
Associate Professor
905-688-5550 x3092
kelly.lockwood@brocku.ca

Steve Dol
MSc Candidate
519-209-4220
sd09lw@brocku.ca

Dear participant,

Thank you for participating in the project entitled “A Cross-Sectional Analysis of Functional Movement Screen Scores in Male AAA Minor Hockey Players”. The purpose of the study was to compare FMS scores when analyzed by chronological age versus stage of maturity as defined by age of peak height velocity in adolescent male ice-hockey players.

One hundred male competitive (AAA) ice-hockey players representing four hockey age categories (Atom n=25, Peewee n=25, Bantam n=25, Midget n=25) were recruited to participate in the study. Outcomes of the study have included individual FMS scores, frequencies of asymmetries, and a comparison of individual vs. group FMS total score.

If you have further questions, please contact Mr. Steve Dol who will be willing to provide further interpretation of the individual FMS screen scores.

Thank you for your participation in this project. A full copy of the thesis will be available at <http://dr.library.brocku.ca/handle/10464/1689> (Search: Dol, Steven)

Regards,

Steve Dol and Dr. Kelly Lockwood